State of California
THE RESOURCES AGENCY

Department of Water Resources

BULLETIN No. 147-1

Ground Water Basin Protection Projects

SANTA ANA GAP SALINITY BARRIER, ORANGE COUNTY

DECEMBER 1966

HUGO FISHER	EDMUND G. BROWN	WILLIAM E. WARNE
Administrator	*Governor*	*Director*
The Resources Agency	State of California	Department of Water Resources

SANTA ANA GAP, 1964

Spence Air Photos

Santa Ana Gap is a coastal lowland in Orange County that was formed by the Santa Ana River during ancient times. The improved channel of the river now carries surface runoff to the ocean along the eastern edge of the Gap.

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DEPARTMENT OF WATER RESOURCES

ENGINEERING CERTIFICATION

This report has been prepared under my direction as the professional engineer in direct responsible charge of the work, in accordance with the provisions of the Civil and Professional Engineers' Act of the State of California.

Wade D Brim
Registered Civil Engineer

Registration No. C 13743

Date September 27, 1966

ATTEST:

J J Doody
District Engineer
Southern District

Registration No. C 6500

Date September 27, 1966

Alfred R. Golzé
Chief Engineer

Registration No. C 12676

Date ____________

FOREWORD

Bulletin No. 147-1, "Ground Water Basin Protection Projects: Santa Ana Gap Salinity Barrier, Orange County", reports on an investigation authorized by Sections 12922 and 12923 of the State Water Code, known as the Porter-Dolwig Ground Water Basin Protection Law. That law provides that the Department of Water Resources shall study measures for the protection of the ground water basins of the State from degradation by sea-water intrusion, refuse disposal, or adverse salt balance conditions.

The investigation reported here is the first in a series to be carried out under provisions of this law. Specifically, this investigation deals with degradation by sea-water intrusion in the ground water basin underlying the Santa Ana Gap area of Orange County.

In carrying out this investigation, the Department received valuable assistance from a number of state and local agencies, private organizations, and individuals. Particular recognition is due the Orange County Water District, City of Fountain Valley, City of Huntington Beach, County Sanitation Districts of Orange County, Orange County Flood Control District, Signal Oil and Gas Company, Standard Oil Company of California, Fairview State Hospital of State Department of Mental Hygiene, Talbert Drainage District, and Talbert Water District. This cooperation is gratefully acknowledged.

This report is a final edition published first as a preliminary edition. Agency and public hearings were conducted by the Department to obtain the opinions of all interested persons and agencies. This final edition reflects the testimony recieved. Comments received in the course of the hearing are on file in the Department's office in Los Angeles.

William E. Warne

William E. Warne, Director
Department of Water Resources
The Resources Agency
State of California
October 10, 1966

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WILLIAM M. CARAH
Executive Secretary

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Engineer

AUTHORIZATION

This investigation was conducted under the auspices of the Porter-Dolwig Ground Water Basin Protection Law of the State of California. This legislation has been codified in Sections 12920 through 12925, Chapter 7.5, Division 6 of the California Water Code as follows:

> "12920. This chapter shall be known as, and may be cited as, the Porter-Dolwig Ground Water Basin Protection Law.
>
> "12921. The definitions in this article govern the construction of this chapter.
>
> "12921.1. 'Department' means the Department of Water Resources.
>
> "12921.2. 'Local agency' means any county, city, state agency or public district.
>
> "12921.3. 'Project' means any physical structure or facility proposed or constructed under this chapter for the conservation, storage, regulation, reclamation, treatment or transportation of water to replenish, recharge, or restore a ground water basin, or to prevent, stem, or repel the intrusion of sea water therein, or to improve the quality of the waters thereof, when such basin is relied upon as a source of public water supply.
>
> "12922. It is hereby declared that the people of the State have a primary interest in the correction of irreparable damage to, or impaired use of, the ground water basins of this State caused by critical conditions of overdraft, depletion, sea-water intrusion or degraded water quality.
>
> "12922.1. The legislature finds and declares that the greater portion of the water used in this State is stored, regulated, distributed and furnished by its ground water basins, and that such basins are subject to critical conditions of overdraft, depletion, sea-water intrusion and degraded water quality causing great detriment to the peace, health, safety and welfare of the people of the State.
>
> "12923. It is the intention of the Legislature that the department shall initiate investigations, studies, plans and design criteria for the construction of any project, or projects, deemed by the department to be practical, economically feasible and urgently needed to accomplish the purposes of this chapter.

"It is the further intention of the Legislature that upon the submission by any local agency, or agencies, to the department of plans and design criteria for any project, or projects, a review, evaluation and any necessary revision of such plans and design criteria shall be made by the department to insure that construction of such project, or projects will accomplish the purposes of this chapter.

"12925. The sum of two hundred fifty thousand dollars ($250,000) is appropriated from the General Fund in the State Treasury to the department to be expended by it during the 1961-1962 fiscal year for the purposes of this chapter."

ABSTRACT

The Santa Ana Gap is a 2-1/2-mile strip of land between Huntington Beach and Costa Mesa in Orange County. Strata of sand and gravel underlying the gap serve as the main outlet for ground waters of the Anaheim Basin to the ocean or, when ground water levels drop below sea level, as a subsurface inlet for sea water. Intrusion of saline ocean waters into the underground water-bearing zones was first noticed in the early 1930's. By 1961 the saline intrusion had progressed inland a maximum of about 4 miles, degrading ground water underlying an area of 6,700 acres. If ground water levels in the Anaheim Basin remain below sea level, the entire basin is threatened by saline water intrusion. / Subsurface geology in the gap is discussed extensively, and several types of subsurface sea-water barriers are presented. / Foldout plates show geologic sections, ground water level elevations, and water quality.

CHAPTER I. INTRODUCTION

The coastal portion of Orange County has been plagued by the intrusion of saline ocean waters into the underground water-bearing zones since the early 1930's, when that intrusion was first noticed in the Santa Ana Gap area. If this saline intrusion is not controlled, fresh ground water supplies within a large part of the Anaheim Basin may be degraded beyond usefulness.

Objectives and Scope of the Investigation

The objective of the investigation described in this report was to formulate general plans for the construction of facilities to prevent the continuation of ground water quality degradation by the landward movement of saline waters in the Santa Ana Gap area.

The scope of the study was limited to a detailed program of geologic, hydrologic, and water quality data collection and evaluation in the gap area shown on Plate 1, "Area of Investigation". Since physical conditions in the Anaheim Basin exert a profound effect on conditions in Santa Ana Gap, the general hydrology of that Basin was considered. However, a more detailed study of the larger area was beyond the scope of this investigation and was not undertaken. The extent of the consideration of remedial measures included their location in the Santa Ana Gap, their physical limitations, and a comparison of their economic merits.

Conduct of the Investigation

The earliest phase of work included review of pertinent reports, reference material, and available basic data. (Appendix A, "Bibliography", lists the many reports related to this investigation, and Appendix B, "Definitions", contains definitions of the many specialized terms encountered.) After review, well location maps, isochlor charts, preliminary geologic cross sections, and a geologic block diagram were prepared. Four aquifers were delineated in the area, and structure contour maps depicting these aquifers and their areas of suspected physical intercontinuity were drawn. Initial field work included a general survey of the areal geology on Huntington Beach and Newport Mesas, location and description of approximately 300 existing water wells, and collection of about 150 ground water samples for mineral analyses. The locations of wells existing at the beginning of this investigation are shown on Plate 2, "Location of Existing Water Wells". Appendix C, "Well Data", lists the pertinent information on these wells and Appendix D, "Mineral Analyses of Ground Waters, Anaheim Basin, Santa Ana Gap", tabulates results of analyses of the samples collected.

A review of the available information indicated that to properly evaluate the complex structural conditions in the gap and any other factors which might control the effectiveness of corrective measures, exploratory holes should be drilled and small diameter wells or piezometers installed. Following meetings with representatives of interested public agencies in Orange County, specifications were prepared for exploratory drilling and piezometer construction at 29 sites. The locations of these sites are shown on Plate 3, "Location of Exploratory Test Holes and Piezometers". Right-of-way negotiations were initiated in February 1962, and many landowners and public agencies were contacted relative to the necessary entry permits. By May 1962, agreements had been consummated for right-of-entry to the 29 sites. Contracts were awarded to Ventura Drilling Service, Incorporated, for the rotary drilling of 12,180 feet of 7-inch diameter test holes and the installation of nine 2-inch piezometers, and to Lane-Wells Company for attendant electric logging services. Construction was started on August 28, 1962, and completed in March 1963. After construction, a second phase of field work was commenced. This encompassed the collection of water samples from the new piezometers, measurement of water levels over the entire area, running of ground water conductivity traverses, and installation and maintenance of continuous ground water level recorders. Aquifer tests were conducted at 10 pumping wells and corresponding measurements were made at 20 observation wells. From these tests, transmissibility coefficients were derived. A summary of the data obtained from these tests is presented in Appendix E, "Aquifer Tests".

In order to derive the maximum amount of data from the 7-inch diameter test holes, cutting samples were logged and analyzed in detail, core and mud samples were collected, and total drilled footage was logged electrically. The nine 2-inch piezometers were installed in individual aquifers and cemented above and below the aquifers to provide hydrologic and water quality data from each water-bearing zone. These piezometers were constructed of 2-inch polyvinyl chloride pipe to provide long-term resistance to the corrosive effect of high salinity ground waters. As a result of the cooperation of the Orange County Water District, 14 additional 1-inch galvanized-iron pipe piezometers were installed. The donation of this pipe by the District facilitated the construction of additional multiple installations; as many as three piezometers were subsequently placed in a single test hole, each tapping a separate aquifer.

Concurrently with construction and contract administration, data from drilling operations were analyzed at a nearby field office. For the purpose of determining correlative stratigraphic units and aquifers, approximately 350 core samples and drill cutting samples were analyzed for their mega- and micro-fossil content. Electric logs were studied in detail and compared with lithologic logs to determine the nature and permeability of the aquifers encountered, and the salinity of the waters they contained. This geologic work also included preparation of structure contour maps showing the top and bottom of the various aquifers and the delineation of cross sections to illustrate aquifer continuity. Electric logs proved to be an invaluable tool for correlation and description of the shape and extent of the saline wedge.

A three-dimensional geologic peg model was assembled to depict the stratigraphic correlation of the exploratory holes. The holes are simulated by graduated rods set vertically in a base which represents an elevation of 700 feet below sea level. The model was built both as an aid in the interpretation of the structural complexities of the gap, and as a representation and explanation of the sequence of aquifers to other interested agencies and the public.

As drilling was proceeding simultaneously with the data analysis, the location and nature of exploratory drilling could be somewhat modified as geologic problems developed. This flexible approach yielded the most valuable information obtainable at each location in the exploratory program.

Subsequent to these information-gathering phases of the investigation, analyses were made of the results of the geologic investigation and of the hydrologic and water quality aspects of the aquifers in Santa Ana Gap. These comprised the preparation of hydrographs showing the fluctuation of water levels in selected wells, and the delineation of water-level contour maps depicting the piezometric surfaces in three of the nine recognized aquifers. Further hydrologic studies included an evaluation of historic ground water overdraft conditions in Anaheim Basin and a consideration of possible future ground water and surface water requirements.

Geologic work involved the completion of 22 geologic correlation sections and the preparation of aquifer structure contour maps. Various methods were then considered to control the incursion of saline waters, including the analysis of detailed salinity barrier schemes and their comparative costs.

Related Investigation and Reports

In the extensive bibliography to this report are several reports of special value in the conduct of this investigation. They are:

California Department of Water Resources. "Report on Studies of Sea-Water Intrusion in Santa Ana Gap, Orange County." Office Report. 1961.

----. "Sea-Water Intrusion in California." Bulletin No. 63. 1958.

Garrett, A. A. "Status of Salt-Water Contamination in the Coastal Part of Orange County, California as of 1950." United States Department of the Interior, Geological Survey. Unpublished release. April 1951.

Piper, A. M., Garrett, A. A., and others. "Native and Contaminated Ground Waters in the Long Beach-Santa Ana Area, California." United States Geological Survey Water-Supply Paper No. 1136. 1953.

Poland, J. F. "Hydrology of the Long Beach-Santa Ana Area, California." United States Geological Survey Water-Supply Paper No. 1471. 1959.

Poland, J. F., Piper, A. M., and others. "Ground-Water Geology of the Coastal Zone, Long Beach-Santa Ana Area, California." United States Geological Survey Water-Supply Paper No. 1109. 1956.

During the period of field studies, the Department was also conducting similar work in the adjacent Bolsa-Sunset Beach area. The data collected in that study confirm postulated geologic and hydrologic continuity between the two areas.

Area of Investigation

Santa Ana Gap is a coastal lowland in Orange County lying between Huntington Beach and Newport Mesas about 30 miles southeast of the City of Los Angeles. This gap was formed by the Santa Ana River, which now carries surface runoff to the ocean along the easterly edge of the gap. Physiographically, the gap is an alluvial valley about 2-1/2 miles in width. It extends about 4-1/2 miles inland (north) from the coast and occupies the southern portion of Anaheim Ground Water Basin. Its surface elevations range from sea level at the coast to about 25 feet at its inland portion, while the adjoining mesa surfaces exhibit elevations ranging from about 50 feet to 110 feet above sea level. The study was conducted over the entire gap and portions of the mesas, an areal extent of approximately 25 square miles, depicted on Plate 1.

State Highway 39 (Beach Boulevard) travels north along the western side of the gap while State Highway 55 (Newport Boulevard) travels northeast about 2 miles southeast of the gap. U. S. Highway 101 Alternate crosses the southern boundary of the gap along the coast. Most of the gap area between Highway 101 and the ocean is occupied by the Huntington Beach State Park,which attracts thousands of recreation seekers each year.

The coastal plain, in which Anaheim Basin lies, is within the climatic regime known as Dry-Summer Subtropical or Mediterranean. Essentially, this climate is characterized by a concentration of a modest amount of precipitation in the winter, with completely dry or nearly dry summers; mild winters; warm to hot summers; and a high percentage of sunshine the year around, especially in the summer. Mountains terminate this type of climate on the inland side, but all of Santa Ana Gap and Anaheim Basin are included in this regime. Annual precipitation on this basin varies from about 12 inches at Huntington Beach to about 15 inches near Anaheim, located about 12 miles inland.

In the past, partially through the use of the winter precipitation, the land in the gap was used primarily for truck crops. The area is now experiencing rapid urban growth and is presently occupied almost entirely by the Cities of Huntington Beach, Fountain Valley, and Costa Mesa, whose populations grew from 11,492, 2,068, and 37,550, respectively, (April 1, 1960, census) to 55,900, 6,400, and 62,500 (April 1, 1964, estimate). Urban development in the gap is mainly in the form of housing, although some commercial buildings are now being constructed.

History of Intrusion

During the 1890's, agricultural interests were attracted to the flat fertile surface of Santa Ana Gap where artesian wells yielded water of excellent mineral quality from the shallow deposits of Recent age. T. B. Talbert (1952), states that:

> "There was water everywhere, water of the finest, purest quality. It goes without saying that there was no need of irrigation. There was never a thought of a pumping plant, nor did anyone in his wildest dreams imagine that there ever could be a shortage

of water. The vital problem was to get enough water drained off the land so that it could be cleared and made productive."

By 1910 the land had been drained. By the middle of the 1920's the increased production of ground water had led to the lowering of pressure levels in the shallow water-bearing zone to elevations below sea level. Consequently, encroachment of water from the ocean began to occur in the shallow zone, named the Talbert aquifer for the community (now part of the City of Fountain Valley) which it underlies.

By 1931 the highly productive Talbert aquifer exhibited chloride ion concentrations exceeding 50 parts per million (ppm) in a region of approximately 2,200 acres near the coast. (Native ground waters in the Talbert aquifer normally exhibit chloride ion concentrations of 15 to 30 ppm.) This area increased to about 2,700 acres by 1944 with the 50 ppm chloride front ranging from about 1 mile inland in the western part of the gap to about 1.5 miles inland in the central and eastern portions. In all instances, the 50 ppm isochlor line was closely followed by waters exceeding 500 ppm. Ground waters containing chloride ion concentrations in excess of 500 ppm could not be beneficially used in the area.

In June 1950, the area underlain by waters of concentration greater than 50 ppm was about 4,000 acres, excluding a supplementary source of impairment evidenced in Section 1, Township 6 South, Range 11 West. This additional impairment is thought to have been caused by the improper disposal of oil field brines on Huntington Beach Mesa.

As the saline waters intruded from 1930 to 1960, there was a progressive increase in the abandonment of water wells. A number of wells tapping the zones below the Talbert aquifer also began to experience intrusion during the latter part of this period.

HUNTINGTON BEACH MESA, 1928 Spence Air Photos

Oil was first discovered in the area in 1920 on Huntington Beach Mesa, and by 1928, a highly productive oil field had developed.

At the initiation of this study in November 1961, the 50 ppm chloride front had progressed inland a maximum of about 4 miles on the west flank and about 3 miles in the central and eastern portions of the Talbert aquifer, degrading an area of approximately 6,700 acres.

During the period 1962-63, the 50 ppm chloride front receded toward the coast, with the areal extent of the intrusion lessening to about 6,500 acres. Saline waters moved seaward one-eighth to one-fourth mile in the western and central portions, while the front remained essentially stationary in the eastern part of the gap. These recent ground water movements have been in direct response to the pressures established by artificial recharge activities in the forebay area, north of the City of Santa Ana.

CHAPTER II. GEOLOGY

The subsurface geology of the Santa Ana Gap area was first studied about 1919 in the quest for oil. The discovery of oil on May 21, 1920, resulted in increased drilling activity which received new impetus with each subsequent production development.

The general geology of the study area as it relates to the occurrence of ground water has been considered by many, notably Eckis (1934) and Poland (1956). The study summarized in this report is supplemental to earlier work by other investigators who did not have the large amount of relatively reliable data now available. These data were obtained from the exploratory drilling program and its associated electric and lithologic logs, micropaleontologic analyses, and core samples, and from a study of the geomorphology and surface geology of the area. The surface geology and the location of geologic cross sections are shown on Plate 4A, "Areal Geology". Areal extent and thickness of peat deposits are shown on Plate 4B, "Location of Peat and Organic Soils". Geologic sections are shown on the Plate 5 series, "Geologic Sections A-A' Through G-G'".

The discussion given here is divided into geologic setting, stratigraphy, and structure of the area.

Geologic Setting

Santa Ana Gap is situated in an ancient marine sedimentary basin that existed throughout most of Tertiary and Quaternary time. The early Tertiary deposits in this basin are generally nonwater-bearing. Of the several thousands of feet of marine sediments laid down, only those of late Pliocene and Pleistocene age are of major water-bearing significance.

All the sediments in this ancient basin have been grossly affected by uplift and lateral movement along the Newport-Inglewood fault zone, and by downwarping in the South Gate-Santa Ana syncline. As a result of these and other structural activities within Orange County, portions of the formerly buried and deep-seated deposits now crop out either on the mesas that flank Santa Ana Gap, or within the Puente Hills and Santa Ana Mountains, north of the gap.

Near the end of Pleistocene time, a major decline in sea level occurred. The Santa Ana River, adjusting to the new lowered base level, eroded a valley about 200 feet deep across the elevated coastal plain between Huntington Beach Mesa and Newport Mesa. Thus, it removed a considerable part of the Pleistocene sedimentary section.

About 13,000 years ago, as the ice age glaciers melted, sea level again began to rise. As sea level rose, coarse alluvial debris (the Talbert aquifer) derived from the San Gabriel and San Bernardino Mountains was deposited in the coastal channel, or gap. Beginning about 9,000 years ago, the rate of sea level rise decreased. Because of the resultant decrease in river gradient, fine-grained sediments were laid down over the coarse alluvium. These fine sands, silts, and clays now constitute the confining layer that overlies the Talbert aquifer.

Stratigraphy

During the investigation, the stratigraphic sequence of Recent and Pleistocene deposits was explored in detail. However, the upper Pliocene sediments were not penetrated by any of the exploratory test holes, and are known only from the study of published records and the analysis of oil-well electric logs. The entire sequence of water-bearing deposits is shown diagrammatically on Plate 6, "Generalized Geologic Column". The following description of materials has been subdivided by lithologic units into upper Pliocene deposits (upper Pico Formation), lower Pleistocene deposits (San Pedro Formation), upper Pleistocene deposits (Lakewood Formation), and Recent deposits.

Upper Pliocene Deposits (Upper Pico Formation)

The upper division of the Pico Formation (upper Pliocene) underlies all of Huntington Beach Mesa and Santa Ana Gap, and portions of Newport Mesa. Beneath the gap, these deposits exhibit a maximum thickness of about 1,000 feet. Along Hamilton Avenue, they have been uplifted to within 350 feet of the ground surface. On Newport Mesa these upper Pliocene deposits thin to a featheredge near the coast. They are highly faulted and folded along the complex Newport-Inglewood structure; apparent vertical displacement locally exceeds 350 feet. North of the structure, the upper Pico beds thicken and dip gently to the north.

These sediments were deposited in a marine environment of moderate depth. Examination of oil well lithologic and electric logs shows them to be composed of partially cemented sand, silt, and clayey silt, with lenses of fine to medium sand. North and northwest of Santa Ana Gap, gravel stringers are found also. The most permeable portions of the upper division of the Pico Formation are collectively designated the "Pico" aquifer in this report.

Lower Pleistocene Deposits (San Pedro Formation)

Lower Pleistocene deposits, known as the San Pedro Formation, overlie the upper Pliocene sediments throughout the Santa Ana Gap area.

The Pliocene-Pleistocene division in the coastal portion of Orange County is based mainly on micropaleontological evidence rather than on a distinct lithologic break, and it is thus somewhat arbitrary. Correlation of the subsurface data existing prior to this study has long been a problem. One investigator stated that,

> ".... in Orange County the deposits of Pleistocene age are markedly heterogeneous and only locally can their component formation be discriminated by available data ...." (Poland, 1956)

Because of the extremely limited extent of surface outcrops, the San Pedro Formation in this area is known almost entirely through the study and interpretation of subsurface oil well and exploratory test hole data. An example of an exploratory well log is shown in Plate 7, "Typical Composite Log".

The San Pedro Formation is composed of clays, silts, sands, and fine to coarse gravels, derived mainly from the erosion of the San Gabriel, San Bernardino, and Santa Ana Mountains. These materials were deposited in a marine basin of moderate to shallow depth. Near the Newport-Inglewood structural crest, the base of the San Pedro Formation is about 350 feet below land surface. To the north, in the direction of the South Gate-Santa Ana syncline, the base is probably more than 1,000 feet below ground surface. The top of the San Pedro Formation varies from 110 feet below land surface near Brookhurst Street and Atlanta Avenue to 300 feet along Slater Avenue in the northern part of Santa Ana Gap. Thus, the thickness of the San Pedro beds ranges from 240 feet in the uplifted area to about 700 feet in the northern part of the study area.

The reduced thickness of the San Pedro Formation in the southern part of the gap is explained, at least in part, by erosion of the uppermost beds during middle and late Pleistocene and early Recent times. North of the Newport-Inglewood system, the formation slopes northward toward the South Gate-Santa Ana syncline with a maximum dip of about 5 degrees. South of the faults, the San Pedro beds appear to dip gently seaward beneath the Pacific Ocean.

The lowest portion of the San Pedro Formation explored by the Department's test wells is composed of a thick sequence of silt, silty clay, and clay, with localized sand and thin gravel lenses. These fine-grained deposits are overlain by a sequence of fine to coarse sands and gravels with interbedded silts and clays. The coarse materials between interbedded fine-grained members have been designated the Main, lower Rho, upper Rho, and Omicron aquifers in upward succession. These units are illustrated on the Geologic Sections, Plates 5A through 5G. Contours on the top of the Main aquifer are shown on Plate 8, "Lines of Equal Elevation - Top of the Main Aquifer". This aquifer occupies approximately the same stratigraphic position as the Silverado aquifer of the Los Angeles Coastal Plain.

Correlation of the San Pedro sand and gravel units throughout the area is difficult because of frequent changes in sedimentary facies and because of lateral movement of beds along the many faults. In the early Pleistocene shallow marine basin, silts were laid down simultaneously with sands and gravels. This produced interfingering beds and abrupt changes in lithology along any one horizon. Subsequent to deposition, the lithologic discontinuities were further disrupted by lateral displacement. To facilitate correlation of units, five micropaleontological horizons were identified in drill cuttings and used as "markers" in the area north of the Indianapolis fault. These fossil horizons are shown on Plate 6. Because of the great differences in fossil content, no positive paleontological correlation could be carried across the Indianapolis fault. However, faunal content identified in strata explored within three wells south of that fault may be intercorrelated. Similarly, no certain correlation of horizons could be carried across from the landward to the seaward side of the North Branch of the Newport-Inglewood fault. For this reason, the aquifer designations in the coarse-grained San Pedro strata south of the Indianapolis fault have been only tentatively assigned.

Upper Pleistocene Deposits (Lakewood Formation)

During mid-Pleistocene time, older deposits were uplifted and the lower Pleistocene sediments were partially eroded. The upper Pleistocene beds were deposited upon the slightly upturned and truncated San Pedro strata. These beds are collectively called the Lakewood Formation in this report. The deposits of the Lakewood Formation form the surfaces of both Huntington Beach Mesa and Newport Mesa and underlie the northern half of Santa Ana Gap. This formation is not present in the southern portion of the gap.

The Lakewood Formation is composed of clays, silty clays, silts, sands, and fine to coarse gravels of continental to very shallow marine origin. These upper Pleistocene sediments are now believed to be substantially thicker than was originally thought. Upper Pleistocene deposits on Huntington Beach Mesa had been considered to be generally less than 100 feet thick. They are now thought to be almost 300 feet in thickness in that area. As a result of this study, the division between the lower

Pleistocene San Pedro strata and the upper Pleistocene Lakewood beds has been placed at the first occurrence of shallow marine microfauna (Nonionella species). Sediments above this horizon contain either very shallow marine fossils or are barren, and are assigned to the Lakewood Formation. Because a local unconformity is present at the base of the upper Pleistocene sediments, the relatively thick Lakewood Formation of this report may also include sediments of mid-Pleistocene age. The relationships discussed above are shown on Plate 6.

As was pointed out above, the total thickness of the upper Pleistocene Lakewood Formation varies from about 100 to 300 feet on Huntington Beach Mesa. Within the northern part of Santa Ana Gap, these beds range from about 400 feet in thickness to a featheredge near Adams Avenue where they have been completely eroded by an ancestral Santa Ana River. In the Newport Mesa area the available data, although meager, suggest that they range from about 350 feet along the northern margin of the mesa to about 10 feet along its southwestern coastal bluffs.

Three aquifers have been recognized within the Lakewood Formation. They have been designated the Lambda, Beta, and Alpha aquifers in upward succession. These water-bearing zones are generally separated by beds of clay, clayey silt, and silt. The Alpha and Beta have been further subdivided by thin, but reasonably extensive, silts and clays.

Recent Deposits

Toward the end of Pleistocene time, a deep valley was eroded between Huntington Beach and Newport Beach, where the ancestral Santa Ana River flowed out to meet the slowly receding sea. During Recent time, this valley was partially filled with continental deposits. These deposits unconformably overlie both the lower Pleistocene San Pedro strata and the upper Pleistocene Lakewood beds. The surface extent of these Recent deposits is shown on Plate 4A.

The deposits of Recent age consist primarily of alluvial debris and floodplain deposits from the inland drainage area. Minor quantities of tidal and lagoonal marsh sediments and beach deposits also occur. Thus, these Recent deposits consist of sands and fine to very coarse gravels with lenses of sandy silt and clay.

Beginning about 9,000 years ago, the coarse-grained beds were in turn overlain by clays, silts, organic silts, and peat, with thin sand lenses throughout. Beds of peat and lenses of organic soils occur within a large portion of these upper fine-grained Recent deposits. These organic soils accumulated in and around fresh-water springs and swamps. Because of prevailing anaerobic conditions during and after burial, the peaty soils were protected from complete decomposition. The thickness of the organic soils ranges from several inches to more than 55 feet. These materials are delineated on Plate 4B, "Location of Peat and Organic Sediments". Radiocarbon age determinations were obtained for organic soil samples cored at exploratory holes SA-19 and SA-20 at depths ranging from 35 to 40 feet. The ages of these samples ranged from 8,030 to 8,140 years old, plus or minus 300 years.*

Recent sediments are relatively uniform in thickness in the center of the gap, varying from about 180 feet in the southern part of

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*These samples were dated by the United States Geological Survey in the Isotope Geology Branch Laboratories. Laboratory sample numbers are W-1406 and W-1407 for the cores from SA-19 and SA-20, respectively.

the area to about 130 feet in the northern part. The Recent materials are consistently thickest along a west-central trough; they thin somewhat along the eastern side of the gap.

South of Adams Avenue, Recent deposits rest directly upon eroded and upturned San Pedro strata. To the north they overlie northward-dipping Lakewood beds. Direct displacement of the Recent unit has not occurred in Santa Ana Gap, although the base of these sediments appears to have been affected by minor folding in a number of localities. The most predominant fold occurs along the trace of the North Branch of the Newport-Inglewood fault.

The lower portion of the Recent unit as described is called the Talbert aquifer. Contours depicting this unit are shown on Plate 9, "Lines of Equal Elevation - Top and Base of the Talbert Aquifer". The physical characteristics of the aquifer are defined in more detail in Chapter III, "Aquifer Units". The silts, clays, and organic material overlying the Talbert aquifer constitute a generally confining member. The top of this confining layer forms the surface of Santa Ana Gap.

Structure

Faulting and folding exert a profound effect upon the stratigraphic continuity of the lower and upper Pleistocene sediments of the Santa Ana Gap area and hence upon movement of ground waters. The salient structural feature of the area is the northwesterly trending Newport-Inglewood fault system. The parallel faults comprising this system have been divided into the Bolsa-Fairview, Yorktown, Adams Avenue, Indianapolis, and Newport-Inglewood North and South Branch faults. A north-northeasterly trending zone of nearly parallel faults has also been identified and tentatively designated the Santa Ana River fault system. The approximate traces of the faults in this system are shown on Plate 4A.

The location and extent of the numerous faults in the Santa Ana Gap area have been determined through surface geologic mapping and study of landform elements, plus a study of the following criteria:

1. Major lithologic and faunal discontinuities between exploratory wells.

2. Major stratigraphic discontinuities in deeper oil-bearing materials.

3. Marked changes in mineral character and quality of ground waters.

4. Abrupt piezometric level differences in aquifers.

5. Anomalies in aquifer performance test data.

These features appear to have been produced by a combination of northwest-southeast trending shearing stresses, which are similar to those of other major structural systems in Southern California, and northeast-southwest trending compressive stresses. The maximal effects are best shown in the disruption of the Tertiary sedimentary section. Faulting and folding are considered here to have been occurring more or less continually since mid-Miocene time. Thus, the greatest displacements occur within the oldest sediments. Displacements are of reduced magnitude upward because of the progressive reduction in the time that younger sediments have been subjected to these structural forces. Within upper Miocene strata, apparent vertical displacements along the North Branch of the Newport-Inglewood fault may be as great as 2,000 feet. Horizontal movements may total 6 miles since middle Miocene time, according to studies of the Huntington Beach oil field conducted by other agencies.

The effects of faulting and folding are of paramount significance to the water transmission characteristics of the lower Pleistocene San Pedro strata. Apparent vertical displacement in these sediments across the North Branch of the Newport-Inglewood fault may be as great as 300 feet. However, lateral displacement of San Pedro beds is of much greater magnitude. Across the major faults, including the Adams Avenue, Indianapolis, and both Newport-Inglewood branches, lower Pleistocene sediments differ markedly in stratigraphy and microfaunal content. These differences cannot be explained by simple vertical separation of beds. From studies of the underlying oil-producing strata and from results of the Department's exploratory program, it is estimated that movements along the Newport-Inglewood fault system may have produced one-half mile or more of horizontal separation in the San Pedro Formation. Also, horizontal movement of a lesser magnitude has probably occurred along the Yorktown and Bolsa-Fairview faults. In general, the seaward blocks have moved in a northwesterly direction, or "up coast" relative to the landward blocks.

Lower Pleistocene strata have also been seriously disrupted by the Santa Ana River fault system, which roughly parallels the river and trends in a north-northeasterly direction. It is comprised of numerous parallel stress relief faults, but the nature and magnitude of displacement are not well known. The many faults of the system are delineated mainly on the basis of marked changes in the mineral quality of ground water between Newport Mesa and Santa Ana Gap. One of the major components of this system was formerly known as the Wright Street or Brookhurst Street fault.

The effects of faulting on the upper Pleistocene Lakewood beds are most pronounced along the Newport-Inglewood fault, North Branch. Where this fault crosses Huntington Beach Mesa, these beds are folded and locally faulted at the surface. Within the gap, Lakewood sediments have been eroded seaward of the Indianapolis fault. Inland of the Indianapolis fault, the lower portion of the Lakewood Formation (Lambda and Beta aquifers) is partially sheared by the Adams Avenue, Yorktown, and Bolsa-Fairview faults and by the Santa Ana River fault system.

Direct displacement within the Recent sediments has not occurred along the faults crossing Santa Ana Gap. However, the base of these deposits appears to have been affected by minor folding, especially along the trace of the Newport-Inglewood fault, North Branch. Therefore, the main body of Recent sediments extends uninterrupted across the zones of faulting with no indication of direct shearing or displacement.

In some areas of Huntington Beach Mesa and Newport Mesa, the major faults extend to the surface and can be studied directly. Surface observation has not as yet yielded any information on the nature or magnitude of horizontal or lateral movement; normal faulting and anticlinal folding predominate. Cursory review of the erosional escarpments that flank the gap suggests a matching of the "nose" near Victoria Street on Newport Mesa with the concavity near Adams Avenue on the edge of Huntington Beach Mesa. The orientation of these surface features might suggest horizontal separation along the Newport-Inglewood fault zone. However, the direction of relative movement indicated by the position of these two adjacent blocks is different from that indicated by most subsurface data. It is probable that these surface features are best explained by chance occurrence or by the alignment of more resistant beds in the ancient path of the river.

Barrier Effects of Structural Features

The barrier effects that are generally so evident along major faults are caused by the interactions of lithologic discontinuities, structural traps, and zones of cementation. In the area investigated, a striking hydraulic discontinuity appears in the Pleistocene aquifers across the Newport-Inglewood fault branches. Certain water-bearing beds of Pleistocene age in the downthrown coastal block have been directly displaced against fine-grained, nonwater-bearing lower Pleistocene beds as shown on Plate 5B. From surface observations it is also known that some cementing materials--calcium carbonates, silica, gypsum, and iron oxides--are deposited locally in the fracture zone. Across the Santa Ana River faults, distinct barrier effects appear in the Pleistocene aquifers. These barrier effects are likewise a result of cementation and local displacement along the faults.

As has been stated, the lower part of Recent deposits (Talbert aquifer) has not been strongly influenced by structural disturbances and therefore offers little or no impediment to movement of water across the Newport-Inglewood fault system. Thus in the Talbert aquifer, which has sustained the heaviest withdrawals, there are no effective barriers against invasion of ocean water.

CHAPTER III. AQUIFER UNITS

To determine what method would be most practical and economically feasible to meet the problem of saline water intrusion in the area of investigation, a detailed knowledge of the characteristics of the aquifers is imperative. For this reason, a separate chapter has been devoted to this subject.

Nine aquifers were delineated within the study area. The hydrologic features of each aquifer are distinctive. At the same time, all are considered to be hydraulically continuous with the forebay of the Anaheim Basin.

Aquifers

The nine aquifers within the Santa Ana Gap area were designated in the study as the "Pico", Main, lower Rho, upper Rho, Omicron, Lambda, Beta, Alpha, and the Talbert. Because of the variation in extent and character, each is described separately.

"Pico" Aquifer (Upper Pliocene Deposits)

Inasmuch as the Department's 29 exploratory test holes and previously existing wells have not penetrated productive Pliocene sediments, the "Pico" aquifer unit is not known in detail.

Oil well lithologic and electric log data indicate that this unit is composed of fine- to medium-grained, partially cemented materials and that it underlies Huntington Beach Mesa, Santa Ana Gap, and a portion of Newport Mesa. These sediments are of variable thickness in the syncline landward from the Newport-Inglewood structural system. The low to moderate permeability of the unit is probably in the range of 200 to 300 gallons per day per square foot (gpd/ft^2) cross section of aquifer under unit hydraulic gradient, wherever it is coarse enough to yield appreciable quantities of water to wells. Permeabilities for the several aquifers are summarized in Appendix E. Note that although localized fresh water occurs within the "Pico" aquifer, no known extraction has been reported in the area of investigation.

Main Aquifer (Lower Pleistocene Deposits)

The Main aquifer, which was penetrated by most of the test holes, consists of fine- to coarse-grained materials separated from the "Pico" by beds of moderately low permeability. Although lower Pleistocene sediments occur throughout the study area, stratigraphic correlation suggests fault interruption in vertical position and attitude. The top of this unit occurs from 175 to 760 feet below ground level. The average thickness of the Main aquifer is approximately 100 feet. A maximum thickness of 200 feet is attained in the vicinity of Garfield Avenue and Cannery Street.

Aquifer test determinations indicate a moderate to high permeability, varying from about 300 to 1,100 gpd/ft^2, as shown in Appendix C. Between 1959 and 1963, several wells tapping this source of ground water were drilled in the area.

Lower Rho Aquifer (Lower Pleistocene Deposits)

The fine- to coarse-grained materials of the lower Rho aquifer zone are found throughout the area except in a few small fault blocks in the eastern portion. Landward from the main trace of the Newport-Inglewood fault zone, the unit is uniformly distributed within the gap and underlies both mesas. It is not identifiable seaward of the North Branch of the

Newport-Inglewood fault. It has a moderate to high permeability ranging from about 300 to 1,100 gpd/ft^2. However, it is relatively thin, and no wells are known to tap only this unit.

Upper Rho Aquifer (Lower Pleistocene Deposits)

A fine-grained separator divides the lower and the upper Rho aquifers. Of the two zones, the lower Rho is the more extensive. The upper Rho aquifer is in hydraulic continuity with the overlying Lambda aquifer in a westerly trending band north of Garfield Avenue at a depth of about 270 feet. This area is depicted on Plate 10, "Areas of Hydraulic Continuity Between Aquifers". The upper Rho aquifer occurs throughout the area north of this band. To the south of the contact, it has only minor isolated occurrences in some of the fault blocks. The depth to the top of the upper Rho varies from 170 to 470 feet. It attains a maximum thickness of about 30 feet in the vicinity of Slater Avenue and Cannery Street. Moderate to high permeabilities of 600 to 1,200 gpd/ft^2 are typical of this zone. However, because the upper Rho aquifer is comparatively thin, it is relatively unimportant as a source of ground water.

Omicron Aquifer (Lower Pleistocene Deposits)

The Omicron aquifer is separated from the upper Rho aquifer by a fine-grained aquitard. Hydraulic continuity between the Omicron and Lambda aquifers occurs along Talbert Avenue at a depth of about 280 feet. Depths to the top of the Omicron aquifer vary from 280 to 490 feet. The average thickness of this aquifer is about 40 feet; its thickest section of 75 feet occurs in the northeastern portion of the study area. Locally, the Omicron aquifer is an important source of ground water, and exhibits permeabilities that range from 600 to 1,200 gpd/ft^2.

Lambda Aquifer (Upper Pleistocene Deposits)

The Lambda aquifer underlies the northern portions of both mesas and the entire gap area north of Adams Avenue. It overlies the lower Pleistocene aquifer sequence and is in hydraulic continuity with the overlying Talbert aquifer in a number of areas along Adams Avenue. The medium- to coarse-grained materials of the Lambda aquifer are encountered at depths ranging from 110 to 430 feet below the ground surface. The aquifer averages about 30 feet in thickness. Data from two aquifer tests indicate the permeability of the zone to be about 1,470 gpd/ft^2. Throughout the study area, permeability values are thought to range from 1,000 to 1,600 gpd/ft^2. Only a few wells in the Santa Ana Gap area produce water from the Lambda aquifer.

Beta Aquifer (Upper Pleistocene Deposits)

The Beta aquifer zone has a smaller areal distribution than the Lambda, occurring primarily in the northern portion of the study area. It is differentiated into as many as three distinct fine- to coarse-grained units (Beta I, II, III), which conformably overlie the Lambda aquifer.

The lowest unit (Beta III) occurs primarily in the northwestern portion where it is separated from the other units by clay sequences. Beta II and Beta I are separated by aquitard materials in the northeastern portion of the area, but are merged in the center portion of the gap, south of Garfield Avenue. Also, the Beta II and Beta I units merge and are in hydraulic continuity with the Talbert aquifer just north of the Bolsa-Fairview fault.

The Beta aquifer zone has an average aggregate thickness of 30 feet. It ranges in depth from about 110 feet along the Bolsa-Fairview fault to a maximum of 320 feet in the northern portion of the gap. Only small quantities of water are produced locally from these sediments. Permeability values for the Beta aquifer are estimated to range from 500 to 1,900 gpd/ft^2.

Alpha Aquifer (Upper Pleistocene Deposits)

The Alpha aquifer zone is also divided into three lithologically similar constituents (Alpha I, II, III), which have a relatively wide areal distribution. They are found beneath the major portion of both mesas, and underlie the gap north of Garfield Avenue. This aquifer zone is in continuity with the overlying Talbert aquifer along Garfield Avenue, and along the western margin of the gap in a strip that extends as far south as the North Branch of the Newport-Inglewood fault. This strip roughly parallels the eastern edge of Huntington Beach Mesa. The Alpha aquifer is more than 100 feet thick locally beneath the mesas, but is considerably thinner in the gap, where it has been partially eroded. In the northern part of the study area, the Alpha aquifer zone is a very important source of ground water. Permeability values in this zone are considered to range from 1,000 to 2,200 gpd/ft^2.

Talbert Aquifer (Recent Deposits)

The Talbert aquifer unconformably overlies lower Pleistocene sediments in the gap south of a line near Adams Avenue, and upper Pleistocene sediments, north of this line. These medium- to coarse-grained materials are uniformly distributed between the mesas and have an average thickness of approximately 70 feet. This unit attains a maximum aggregate thickness of about 100 feet within the area of deepest erosional stripping and is as thin as 60 feet in the northern portion of the gap. The top of the Talbert aquifer varies from 50 to 100 feet below land surface.

The Talbert aquifer, the most important source of ground water in the gap area, exhibits high permeabilities varying from 1,900 to 2,500 gpd/ft^2. This unit is overlain by fine-grained sediments of relatively low permeability and organic soils of moderate permeability.

Aquifer Units Subject to Saline Intrusion

As of 1963, the Talbert aquifer had sustained the farthermost inland advance of saline water. Seaward of the Indianapolis fault barrier, most of the moderately to highly permeable Pleistocene sediments had by that date been affected by sea-water intrusion to some degree. This suggests that, seaward of this fault, the Pleistocene aquifers were at some time in the late geologic past in partial hydraulic continuity with the ocean.

Landward of the Indianapolis fault barrier, local intrusion of the Lambda has occurred, specifically within and adjacent to the area where the Lambda is merged with the Talbert aquifer. This condition, in turn, presents a potential intrusion threat to the upper Rho and Omicron aquifers because these aquifers are merged to the north with the Lambda, as shown on Plate 5B. Plate 11, "Lines of Equal Elevation - Base of the Lowest Zone Subject to Saline Water Intrusion", depicts the bases of these three zones. The overlying Alpha and Beta aquifers are also subject to intrusion as a result of their local mergence with the Talbert aquifer.

Additional details on saline intrusion are presented in Chapter V, "Ground Water Quality".

Structural Barriers to Flow

The Newport-Inglewood structural system exerts a barrier effect within the lower Pleistocene aquifers along its entire reach from Huntington Beach Mesa to Newport Mesa. This feature is substantiated by available geologic, hydrologic, and water quality data.

Although degradation might occur locally in the landward portion of the mesas, the fault zone interposes an effective barrier to the movement of fluids across it. In the gap, saline water intrusion has occurred in the Pleistocene sediments across the North and South Branches of the Newport-Inglewood fault system to as far inland as a few hundred feet past the North Branch. North of these faults, strata of silt and clay have been faulted up against the Main, lower Rho, and upper Rho aquifer zones at the Indianapolis fault. These features have formed relatively complete impediments to the continuation of inland saline movement within the lower aquifers. To the north, the Adams Avenue, Yorktown, and Bolsa-Fairview faults offer partial barrier effects to water circulation. Although continuity would appear to exist in some localities along the fault zones where coarse sediments are faulted against other coarse sediments, cementing along the fault zones has apparently helped reduce permeability.

It might be noted that in the Bolsa-Sunset area, the relative ages of waters on opposite sides of the Newport-Inglewood fault have been determined by radiocarbon methods. The water samples dated were obtained from two wells perforated in the lower Pleistocene San Pedro Formation. One well, 5S/10W-32A1, is located seaward of the fault. The other well, 5S/11W-29C2, is located on the landward side. The apparent ages of the ground waters are as follows:

5S/11W-29C2 = 4,030 $\pm$ 230 years

5S/10W-32A1 = 5,700 $\pm$ 160 years

It is probable that the actual age difference is greater than the 1,700-year difference shown above. The older waters seaward of the fault have thus probably been modified by movement of fairly young saline waters into the seaward block from offshore outcrops. In any case, this marked age difference is yet another indication of the major barrier effect exerted by the Newport-Inglewood zone of faulting.

The Santa Ana River fault system, located on the eastern flank of the gap, trends approximately normal to the major structural pattern. The impediment to ground water flow along this structural system is substantiated mainly by differences in quality and character of ground waters.

Although the base of the Recent deposits appears to be affected by minor folding across the Newport-Inglewood fault system, no direct displacement is discernible within the sediments themselves. Ground waters appear to move in an unrestricted manner within the Talbert aquifer across the structural zone.

CHAPTER IV. HYDROLOGY

Santa Ana Gap constitutes only a small part of Anaheim Ground Water Basin. It is, however, a very important portion since it serves as the main outlet for basin ground waters, or subsurface inlet for sea water. In order to determine the magnitude and extent of any sea-water barrier, cursory evaluation of the entire Anaheim Basin is necessary.

Anaheim Basin, as shown on Plate 1, "Area of Investigation", covers an area of 330 square miles. It is replenished naturally and artificially in the forebay area of the basin, which occurs generally north of the Santa Ana Freeway. Ground water extracted anywhere within Anaheim Basin directly affects water levels in the Santa Ana Gap area.

The discussion of the hydrology of Anaheim Basin is developed in the following sequence: Historic ground water conditions in Anaheim Basin and Santa Ana Gap, water supply and utilization in Anaheim Basin, including local basin yield and available imported supply, water utilization and cumulative ground water deficiency, the effect of cumulative deficiency upon water levels from 1944 to 1963, possible elevation of future water levels within the Santa Ana Gap under planned operation, and waste water reclamation, and barrier water requirements.

Historic Ground Water Conditions

Historic ground water conditions are discussed in the following paragraphs on Anaheim Basin, in general, and on the Santa Ana Gap area, in particular.

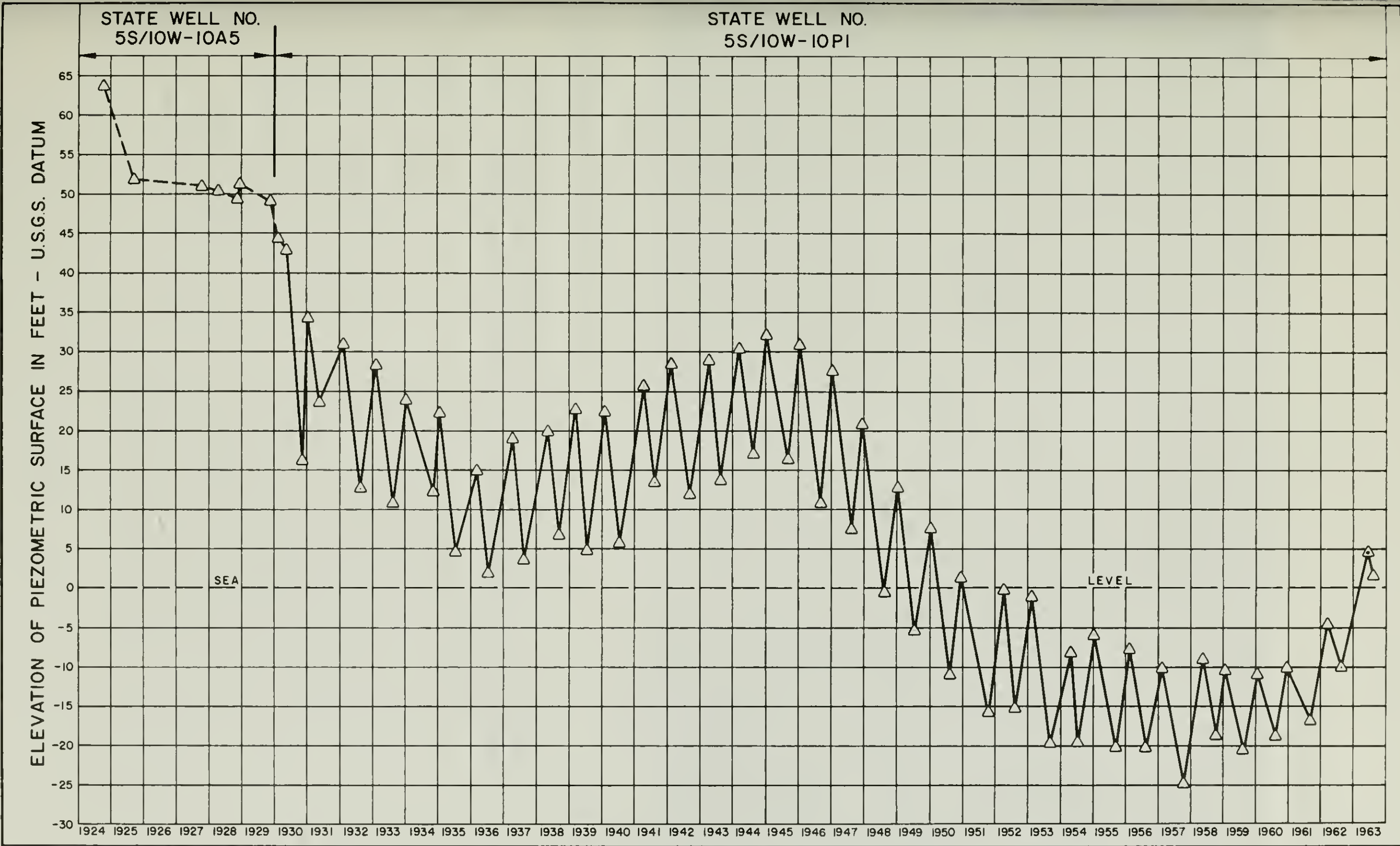
Anaheim Basin

Anaheim Ground Water Basin, which includes Santa Ana Gap, is a coastal synclinal basin with a forebay area and a pressure area. The forebay area lies northeast of a line that roughly coincides with the Santa Ana Freeway. Surface waters can percolate freely to the water table in the forebay. Seaward of this line, ground water occurs under artesian pressure in aquifers which are interbedded with sediments of low permeability. Percolation of surface waters to the aquifers in the pressure area is greatly restricted.

As early as the mid-1920's, a net deficiency of water supply existed in Orange County. This deficiency caused dewatering of a portion of the ground water reservoir; in turn, lowering of ground water levels to elevations below sea level resulted in the intrusion of saline waters. A wet period during the years 1936 to 1945 replenished the ground water reservoir and partially restored historic high water levels. During the period immediately following 1945, ground waters were extracted in quantities which exceeded natural annual fresh water recharge, and a rapid decline in ground water levels ensued.

In 1949, waters were purchased by the Orange County Water District which were imported through the facilities of The Metropolitan Water District of Southern California (MWD). Some of these waters were spread for ground water recharge. Additional water has been spread each year since 1949, and the ground water reservoir has been replenished to a point where declining water table conditions are reversed. From 1957, when the spreading program was expanded, to 1962 there was an annual surplus water supply. The annual surplus slowly reduced the existing deficiency and water levels rose. The rise in water levels after 1959 is shown graphically on Figure 1, "Fluctuation of Piezometric Surface, 1924 through 1963, State Well Numbers 5S/10W-10A5 and -10P1". These wells are located along Bolsa Avenue (3 miles north of Talbert Avenue).

FIGURE 1



FLUCTUATION OF PIEZOMETRIC SURFACE, 1924 THROUGH 1963
STATE WELL NUMBERS 5S/10W-10A5 AND -10P1

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1965

Santa Ana Gap Area

Ground water in the Santa Ana Gap area, a part of Anaheim Basin Pressure Area, is confined by overlying bodies of relatively impervious materials and escape of water from the aquifers to the surface is retarded. Pressure is developed in this area by the weight of a continuous water body which extends to the collecting area in the Anaheim Basin forebay. Static water levels in wells in the pressure area are reduced below the static level in the forebay by friction of percolation.

Prior to the turn of the century, water wells in the gap area yielded artesian flows. Under natural conditions, the aquifers discharged through offshore exposures on the ocean floor and through numerous springs in the gap area. Fresh water springs were also prominent along the edges of the mesas. As water production in the gap increased between 1900 and the middle 1920's, pressure levels declined to elevations near sea level and were temporarily reduced to below sea level during periods of heavy pumping. Discharge of fresh water to the ocean ceased about 1930 as inland pressure levels dropped to elevations below sea level. At that time, salt water began moving into the Talbert aquifer. Water levels, although reduced in height, were still under piezometric pressure. This condition was caused in part by the pressure of the ocean on the shallow aquifers near the coast. The deeper aquifers, such as the Main, were still pressurized only by ground water in the forebay. Although inland ground water production continued to increase through the 1930's, water levels in the Talbert aquifer never declined to more than 15 feet below sea level in the study area. This historic behavior of water levels attests to both the high degree of continuity between the aquifer and the ocean, and the aquifer's high permeability.

AGRICULTURAL USE OF LAND IN 1941 Spence Air Photos

The land in the Santa Ana Gap was used primarily for truck crops in the past but is now experiencing rapid urban growth.

During the late 1930's and early 1940's a series of wet years occurred. With the resultant increase in ground water recharge, pressure levels in the Talbert aquifer exhibited a significant rise. During this period, saline waters which had invaded the aquifer during the 1930's were partially repelled. In the years following this partial recovery, increasing extractions and a series of dry years resulted in a recurrence of the adverse effects of overdraft. Water levels again declined, and by the middle 1950's approached a mean annual level near Bolsa Avenue of about 22 feet below sea level.

As mentioned above, in 1949 the Orange County Water District initiated a program of ground water replenishment through spreading imported waters in excess of that amount required for immediate utilization by the coastal plain area. By 1962, ground water pressure levels in the Talbert aquifer in the northern part of the gap had returned to an average of about 12 feet below sea level due to artificial recharge in the Anaheim Basin forebay and to curtailed pumping from areas which had been invaded by sea water.

Ground water levels in the Talbert aquifer during late spring 1963 ranged from sea level along the coast to about 6 feet below sea level along the northern perimeter of the study area. Slight anomalies in this general pattern have been traced to effects of local pumping and to ground water flow resulting from mergence with underlying aquifers. Ground water pressure levels in the Talbert aquifer are shown on Plate 12, "Lines of Equal Piezometric Elevation -- Talbert Aquifer, Spring 1963".

Conditions during this same period (spring 1963) in a number of the lower water-bearing zones indicate recharge through areas of mergence with the overlying Talbert aquifer. From these areas of mergence, ground waters move generally northward and toward the north ends of both Newport and Huntington Beach Mesas.

In the Alpha aquifer, water surface elevations range from about 3 feet below sea level in the gap to about 10 feet below sea level beneath the adjacent mesas. In the Main aquifer, ground water movement is controlled primarily by fault barriers and by localized extraction. In general, movement is toward a pumping depression near the intersection of Adams Avenue and the Santa Ana River, and toward another pumping depression in the northwestern portion of Huntington Beach Mesa. Elevation of the piezometric surface in the Main aquifer during 1963 ranged from plus 2 to minus 20 feet, mean sea level datum. Extensive measurements made in the study area on May 28, 1963, indicate a maximum difference of 8 feet in piezometric water surfaces of the Talbert, Alpha, and Main aquifers. This offers evidence that direction of ground water movement is locally different in the several aquifers. A comparison of water level fluctuations in the different aquifers during 1963 is shown on Figure 2, "Elevation of Piezometric Surface in the Talbert, Beta, Lambda, Alpha, and Rho-Main Aquifers, Anaheim Basin Pressure Area, 1963". Additional information is presented on Plate 13, "Lines of Equal Piezometric Elevation -- Alpha and Main Aquifers, Spring 1963".

Recharge to the Main and lower Rho aquifers appears to originate only from the basin forebay. The remaining aquifers are recharged from the forebay of Anaheim Basin, from inflow along areas of mergence with the Talbert aquifer, and through mergence with the Lambda, Beta, and Alpha aquifers.

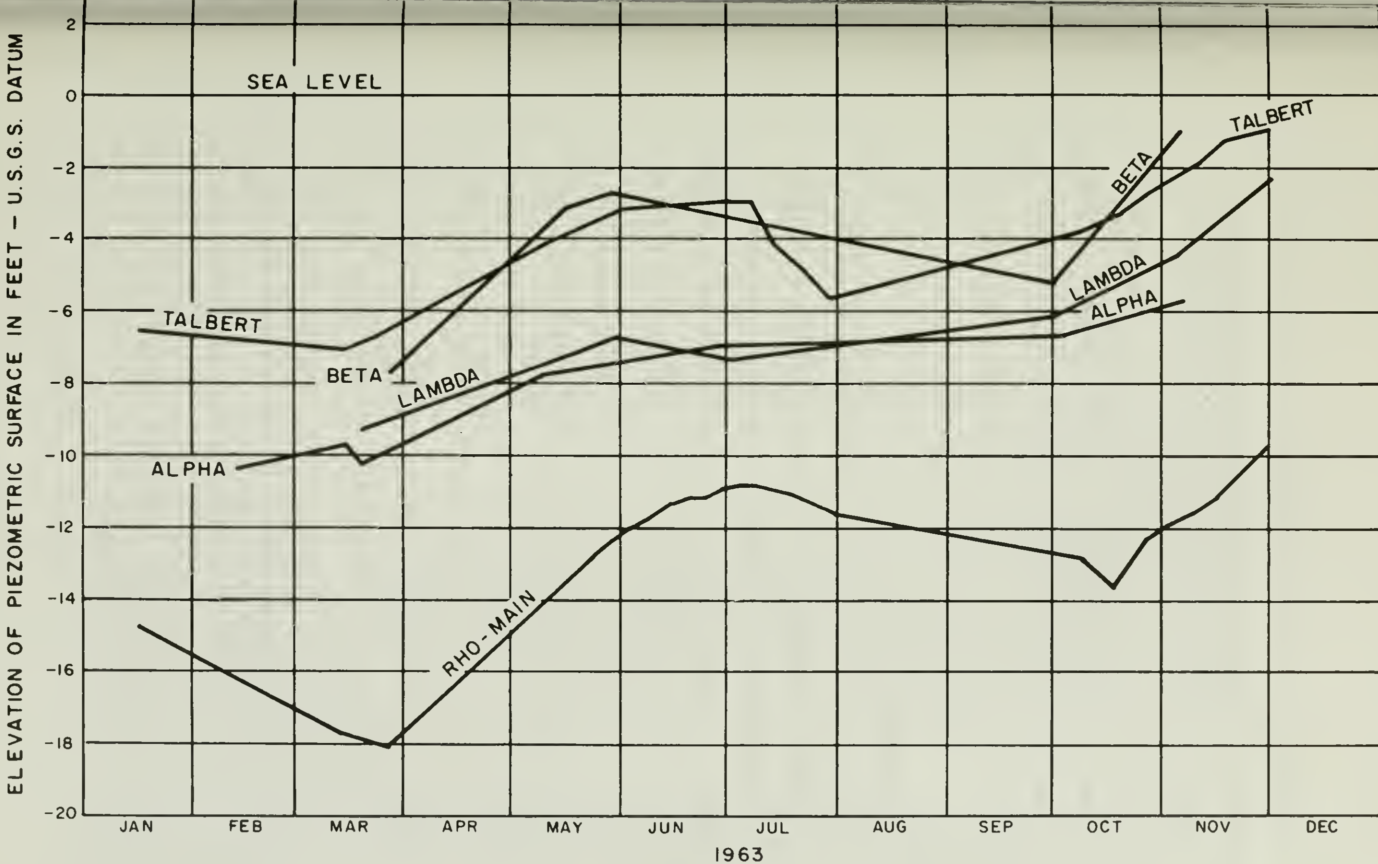
Anaheim Basin Water Supply and Utilization

To determine the approximate quantities of water required for any dynamic salinity barrier (injection ridge, extraction trough, or combination system, as discussed later in Chapters VI, VII, and VIII) in Santa Ana Gap, it is necessary to make some realistic assumption of possible future minimum ground water levels in the basin. To provide information to assist in making these assumptions, the historic water levels under various conditions of water supply were considered.

The following section of this report is subdivided into discussions of local and imported supplies, waste water reclamation, water utilization, and possible conditions of water surplus or deficiency.

Local and Imported Water Supplies

The water needs of the coastal plain of Orange County are satisfied from local water resources and from imports. The safe yield, or natural supply, of the local ground water basin was determined to be about 145,000 acre-feet annually in Department of Water Resources Bulletin No. 70, "Orange County Land and Water Use Survey, 1957". This figure was based on studies made in connection with preparation of State Water Resources Board Bulletin No. 2, "Water Utilization and Requirements of California", and State Division of Water Resources Bulletin No. 53, "South Coastal Basin Investigation, Overdraft on Ground Water Basins". In considering past conditions for this report, the historic safe yield of local ground water supplies was assumed to be 145,000 acre-feet per year, as previously determined. It must, of course, be realized that any safe yield value can only be determined for a particular set of physical conditions and for the stage of development existing at the time the calculation is



ELEVATION OF PIEZOMETRIC SURFACE IN TALBERT, BETA, LAMBDA, ALPHA, AND RHO-MAIN AQUIFERS, ANAHEIM BASIN PRESSURE AREA, 1963

FIGURE 2

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1965

made. Considering the effects of present and probable future surface development of the coastal plain of Orange County, considering the probable increased use in the upper Santa Ana Basin, and allowing for planned operation1/ of Anaheim Basin, it appears that a reasonable future value for safe yield may be on the order of 125,000 acre-feet per year.

Imported water into Orange County has come from the Colorado River through the facilities of MWD. Historical values of imports, up to and including 1962-63, were obtained from records of the Orange County Water District and are presented in Table 1.

Future water supplies will be obtained from the ground water basin, from the Colorado River, and from the State Water Project, through Metropolitan Water District facilities. The future annual local ground water supply, as mentioned earlier, is estimated to be 125,000 acre-feet.

It is possible to estimate future imports of Colorado River water based on the March 1964 decrees of the United States Supreme Court in the action Arizona vs. California2/ and estimates of future water uses in the Colorado River Basin. It is assumed that sufficient water will be made available to the Colorado River Basin area to assure the continued availability of a minimum of 4.4 million acre-feet annually to California. Because of these factors, it is expected that the supply from the Colorado

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1/ The Orange County Water District has been spreading imported water in a program of basin replenishment. It finances this program through a pump tax. Effluent from the County Sanitation Districts of Orange County is being considered as a water supply for injection in a sea-water intrusion barrier in the Santa Ana Gap. This is part of an over-all basin utilization program. The District has shown that it intends to continue its function as a management organization in implementing a program of planned operation of Anaheim Basin.

2/ 376 V.S. 340; 845. ct. 755 (1964)

TABLE 1

WATER IMPORTED TO ORANGE COUNTY THROUGH
METROPOLITAN WATER DISTRICT FACILITIES

In acre-feet

Season ending September 30	Softened and unsoftened water for direct use	Unsoftened water for ground water replenishment	Total
1940-41	1,456	--	1,456
42	772	--	772
43	735	--	735
44	4,264	--	4,264
45	9,172	--	9,172
1945-46	10,908	--	10,908
47	10,982	--	10,982
48	12,274	--	12,274
49	12,902	4,669	17,571
50	13,190	25,267	38,457
1950-51	14,980	28,468	43,448
52	17,591	38,157	55,748
53	18,572	28,891	47,463
54	21,937	61,047	82,984
55	26,504	52,442	78,946
1955-56	23,009	21,702	44,711
57	45,893	102,426	148,319
58	36,108	83,147	119,255
59	55,113	76,013	131,126
60	58,583	169,496	228,079
1960-61	81,970	141,337	223,307
62	71,846	219,243	291,089
63	86,442	199,367	285,809

River, available to the MWD, will be 1,212,000 acre-feet per year through 1971, after which Northern California water from the State Water Project will be available. Imports of Colorado River water to Orange County reached a maximum of 291,000 acre-feet in 1961-62, but are expected to decrease to 120,000 in 1970-71 because requirements are increasing throughout Southern California. Therefore, other MWD members will demand all of their needs, which will restrict the quantities of water available to Orange County. It is assumed that almost all members of the MWD will require their full preferential quotas of Colorado River water by that time.

Construction of a second barrel to the Los Angeles Aqueduct to import additional water from Mono Basin and Owens Valley to the City of Los Angeles will be initiated in the near future. The second barrel is expected to be in operation by 1968 and will deliver 152,000 acre-feet annually. This will release part of Los Angeles' use of Colorado River water for use by other Metropolitan Water District members and it was considered in the estimate of Colorado River water imports to Orange County.

In recognition of the reduced diversion by the Metropolitan Water District from the Colorado River, the planned annual yield of the State Water Project was increased in 1964 from 4,000,000 acre-feet to 4,230,000 acre-feet. It is expected that water from the State Water Project will be delivered to Southern California beginning in 1972. Of the 4,230,000 acre-feet yield, Metropolitan Water District has contracted for a maximum annual entitlement of 2,000,000 acre-feet. It is expected that 250,000 acre-feet will be delivered to MWD in 1972. This quantity will steadily increase to 2,000,000 acre-feet by 1990.

As stated above, the State Water Project now under construction has a prospective yield of 4,230,000 acre-feet per year. It is the initial unit of The California Water Plan. This first stage is designed to satisfy the need for supplemental water in the State Water Project service area up to about 1990. Water requirements after 1990 will be met by additional units of The California Water Plan.

Waste Water Reclamation

Two treatment plants in the Santa Ana Gap process waste waters from the coastal plain. Where possible, the more saline waste waters are segregated and treated at Plant No. 2, while better quality wastes are treated at Plant No. 1. The locations of these treatment facilities are shown on Plate 15. Waters which reach Plant No. 1 are derived from extractions from the local ground water reservoir, and also from importations from the Metropolitan Water District. The total dissolved solids concentrations in these sources of supply are approximately 300 to 1,000 parts per million (ppm) and 650 ppm, respectively. Recent studies show that the total dissolved solids content in water reaching Orange County's sewage treatment plants is at least 300 ppm higher than the original concentration in the supply water. If 700 ppm is assumed to be the average in the supply water, a 300 ppm increment from use results in waste water containing a minimum of 1,000 ppm of dissolved solids.

During the 1963-64 fiscal year, Plant No. 1 processed approximately 31,000 acre-feet of waste water. It is anticipated that this quantity will increase at the rate of approximately 10 percent per year.

These waste waters, which are marginal for many direct beneficial uses, would have potential limited use for industry, recreation, and also for agriculture, such as the irrigation use formerly practiced by the Talbert Water District. These waters might serve, with proper treatment, as a continuously available source of supply for injection barrier purposes. However, such use is subject to the approval and control of the State Department of Public Health.

Water Utilization

Estimates of historical and future water utilization were based on studies made for Department of Water Resources Bulletin No. 70, "Orange

County Land and Water Use Survey, 1957"; and Department of Water Resources Bulletin No. 78, Appendix D, "Economic Demand for Imported Water", which the Department is now updating. Historic and projected population figures for Orange County through 1970 are shown in Table 2.

TABLE 2

ORANGE COUNTY POPULATION

Year	Population	Year	Population
1940[a]	130,760	1955[c]	366,900
1944[b]	178,550	1956[c]	440,900
1945[b]	183,350	1957[c]	516,000
1946[b]	189,600	1958[c]	578,000
1947[b]	196,950	1959[c]	643,500
1948[b]	202,600	1960[a]	703,925
1949[b]	213,500	1961[c]	798,900
1950[a]	216,224	1962[c]	880,000
1951[c]	234,800	1963[c]	968,500
1952[c]	256,700	1964[c]	1,056,900
1953[c]	281,000	1965[c]	1,113,200
1954[c]	312,700	1970[c]	1,473,800

a. U. S. Census (April 1)
b. California Taxpayers Association (end of year)
c. California Department of Finance (July 1)

Historical data on land use were available for the survey years of 1942, 1948, and 1957. Annual values of approximate water utilization based on land use values were straight-line estimates between these figures. Predicted values of utilization were developed from projected population and irrigated crop acreages by utilization of appropriate values of net unit water use. The net unit water use for population reflects total water use for domestic, commercial, and industrial activities in urban areas, less the expected return of water to ground water basin storage. Analysis of urban water use within Orange County in cities having relatively little industrial development, as well as in those having a substantially higher level of industrial activity, has shown that the degree of industrialization does not appear to materially affect the range of per capita water consumption. This is apparently the result of dilution of industrial water use by large amounts of domestic water consumption, coupled with the general absence of industrial plants with extremely high water use. Since these conditions are expected to prevail throughout the period of projection, commercial and industrial water uses were treated as parts of the overall unit of urban water use.

Estimates of agricultural water requirements were obtained from Bulletin No. 78, Appendix D. These were examined in light of the development within the county in the seven years since they were originally projected and found to be consistent with that development.

Projected values of net unit urban water use, total net urban requirements, net agricultural requirements, and total net Orange County requirements are shown in Table 3. Total projected net requirements for Anaheim Basin which were developed from these county totals, as well as historical values of water utilization for the basin, are presented in Table 4.

TABLE 3

PROJECTED WATER REQUIREMENTS IN ORANGE COUNTY

In thousands of acre-feet per year

Year	Net unit urban water requirements*	Total net urban requirements	Net agricultural requirements	Total net requirements
1965	0.196	218	117	335
1970	0.204	301	94	395

*Acre-feet per capita per year

TABLE 4

HISTORICAL AND ESTIMATED VALUES OF WATER UTILIZATION
ANAHEIM BASIN

In acre-feet

Water year October 1 - September 30	Utilization
1944-45	241,000
45-46	237,000
46-47	233,000
47-48	229,000
48-49	230,000
1949-50	230,000
50-51	231,000
51-52	232,000
52-53	232,000
53-54	233,000
1954-55	234,000
55-56	234,000
56-57	235,000
57-58	241,000
58-59	247,000
1959-60	253,000
60-61	261,000
61-62	268,000
62-63	275,000
63-64	282,000
1965-66	300,000
1970-71	351,000

Possible Conditions of Water Surplus or Deficiency

Surplus (an excess of supply) results in replenishment of the ground water reservoir, while deficiency (too little supply to satisfy utilization) results in a net withdrawal from the ground water reservoir. A net withdrawal results in a lowering of ground water levels, together with reduced aquifer pressures and localized dewatering of aquifers.

In years of surplus, water first enters and fills the evacuated storage space and then restores artesian conditions. If conditions of surplus continue, excessive replenishment is followed by waterlogging and waste of water to the ocean, depending on the volume of recharge and storage capacity available. Historically, artesian conditions have existed in portions of Anaheim Basin. They would be expected to recur if the recent trend in artificial recharge of surplus water were continued without a corresponding increase in utilization.

To explore past conditions of water supply and water demand, cumulative surplus or deficiency in the basin was considered. It was determined that 1945 ground water conditions would serve as a convenient storage reference because the basin was relatively full at the end of a wet period. Accordingly, an arbitrary value of zero cumulative surplus or deficiency was assumed at the beginning of the water year of 1944-45, and annual surplus or deficiency and cumulative surplus or deficiency were considered through 1970-71.

These considerations indicate that withdrawals from the ground water basin between 1944-45 and 1955-56 produced a yearly deficiency of supply, which resulted in a maximum historic cumulative deficiency by about 1956. The benefits of spreading imported waters are especially evident from 1956 through 1963 when the existing cumulative deficiency had been changed to an apparent cumulative surplus. In the future, under planned operation of the ground water basin, it is expected that ground water levels will be lowered below sea level as the relatively inexpensive ground water is utilized, thus providing storage space for the recharge of local and imported waters.

The effect of changes in the amount of ground water stored in Anaheim Basin upon piezometric levels in the vicinity of Bolsa Avenue can be observed in a general way on Figure 1. As described in previous paragraphs, the mean annual piezometric elevation along Bolsa Avenue can be expected to again drop below sea level in the future under planned operation of the ground water basin.

Barrier Water Requirements

One of the primary reasons for considering historic hydrologic conditions and future utilization of water in Anaheim Basin was to develop an understanding of probable elevations of water levels in the study area during the future. This information is necessary before an evaluation of water requirements for a dynamic salinity barrier can be made.

In order to determine quantities of water necessary for a dynamic barrier to adequately protect the basin from saline invasion, certain parameters must be established. One of these parameters is the height of fresh water required, at any barrier alignment, to repel saline waters at whatever depth they occur. Another condition necessary is knowledge about the probable slope of the ground water gradient away from or toward the dynamic barrier. One method to determine the slope is to locate the area of lowest future water levels in Anaheim Basin and predict the elevation of water levels in that trough on the basis of projected cumulative ground water surplus or deficiency. Difficulties in this method include not only the inherent uncertainties in the estimates of future supply and requirements, but also uncertainties as to the areal distribution of future ground water extractions, and uncertainties in the regimen of artificial recharge. For these reasons, the "basin trough" method was not adopted.

Another method is to consider the slope directly. Selection of this future ground water slope landward from the barrier was based upon the following:

1. Anaheim Basin will be operated in accordance with an optimum plan of water utilization using local and imported supplies to meet expected water needs. (A salinity barrier is considered to be one component in the overall plan of basin management.)

2. Probable future pumping patterns will cause the future "basin trough", or area of lowest water levels, in Anaheim Basin to be located inland of Bolsa Avenue. Bolsa Avenue is located 3 miles north (inland) of Talbert Avenue, shown on Plate 2.

3. In consideration of historic ground water levels under various magnitudes of surplus and deficiency, future water levels along Bolsa Avenue will decline to mean annual elevations approximating 30 feet below sea level.

For purposes of comparing a number of types of barriers under more extreme water level conditions, a level of 50 feet below mean sea level along Bolsa Avenue was also used in the computation of barrier water requirements.

With an estimate of future elevations along Bolsa Avenue and data on characteristics of the subsurface sediments, it is possible to calculate the annual water requirements for operation of dynamic barriers against saline water intrusion along various alignments. These determinations are necessary so that the several alternative types of barriers may be compared, and an optimum plan selected. Water requirements enter into the evaluation of injection and extraction barriers, and combination injection-extraction barriers. The method used to determine water requirements for a barrier is as follows:

1. Select the desired alignment for the proposed barrier.

2. Determine depth of protection necessary.

3. Divide the alignment into segments according to the transmissive characteristics of the sediments.

4. Determine barrier water requirements using the gradient from the "mound" or "trough" at the barrier to an adjacent control area (i.e., Bolsa Avenue or the ocean outcrop). Water requirements are then computed by the formula:

$$Q = T_1 I_1 W_1 + T_2 I_2 W_2 \ . \ . \ . + T_n I_n W_n$$

Where:

Q = flow in gallons per day;

T_1 = transmissibility of water through a 1-foot wide cross section of aquifer being recharged in segment 1, in gallons per day per foot for a hydraulic gradient of 100 percent;

I_1 = hydraulic gradient in segment 1 from the barrier to the control area, in feet per foot;

W_1 = width of segment 1, in feet.

Using this method of analysis, water requirements were computed for extraction barriers, injection barriers, and combination injection-extraction barriers at five preliminary alignments in the study area. Results of the computations of water requirements for those alignments finally selected are included in Chapter VIII, "Costs of Salinity Barriers".

CHAPTER V. GROUND WATER QUALITY

The ground waters in the Santa Ana Gap area of Orange County are characterized by a wide range, both areally and vertically, in the type and concentration of chemical constituents. They include native waters (waters whose chemical character is historically "natural" to a particular water-bearing zone or locality), connate waters (waters which are usually highly mineralized, entrapped in the interstices of the sedimentary rock at the time of deposition), postnate waters (waters which have partially or completely replaced connate waters), and degraded waters (waters whose native character has been modified by the influx of sea water, oil-field wastes and brines, or other saline sources).

Presented in this chapter is a discussion of the collection and interpretation of data, water quality criteria, and ground water quality of the major aquifers in the gap. Plate 14, "Chloride Ion Concentrations In Ground Water" shows various lines of equal chloride ion concentration for the period between 1931 and 1963, and the area underlain by degraded water in 1963.

Collection and Interpretation of Data

During the course of the field studies, approximately 150 samples of ground water were collected from existing water wells and from piezometers installed as part of the investigation. Complete mineral analyses were made of these samples. Additional data on water quality were obtained from other agencies and from written reports pertaining to the Santa Ana Gap area.

Electric logs obtained from exploratory holes drilled during the investigation were examined in detail relative to their salinity implications.

As a result, the shape of the intruding saline wedge in the Talbert aquifer was clearly delineated where test holes passed through that interval. In addition, it was found that through the use of "formation resistivity factor" methods, approximate ground water salinities could be calculated in areas where no mineral analyses were available. In general, the measured resistivity of an aquifer is dependent only on the porosity of the aquifer and on its pore fluid salinity. If mineral analyses of the pore fluid can be made, the porosity, or "formation resistivity factor", can be determined. Conversely, where no mineral analyses are available and when the "formation resistivity factors" for the different aquifers have been determined, those factors can be used to determine the salinity of the water contained within the aquifer from resistivity curves. These concepts may be simply stated as follows:

$$\text{Resistivity of pore fluid} = \frac{\text{true bed resistivity}}{\text{"formation resistivity factor"}}$$

and

$$\text{Salinity of pore fluid} = \frac{6850}{\text{Resistivity of pore fluid}}$$

In these considerations, salinity is expressed in parts per million of total dissolved soids, with resistivity in ohm-meters. Using these methods, the understanding of ground water quality problems was enlarged significantly.

In existing water wells and in the plastic piezometers installed by the Department, vertical conductivity traverses were made with temperature compensating conductivity bridge equipment. Data thus obtained were useful in further analyzing the saline wedge, and in isolating the exact location of the wedge interface separating fresh and saline waters, where wells were perforated throughout one or more aquifers.

Water Quality Criteria

Whether a ground water of a given quality is suitable for a specific purpose depends on the criteria and standards of acceptable quality for that use. Water quality criteria, as adopted by the Department of Water Resources, for irrigation, municipal, and domestic uses are presented in this section.

In water solution most inorganic salts will dissociate into positively charged particles (cations) and negatively charged particles (anions). A complete chemical analysis will commonly include the cations -- calcium, magnesium, sodium, and potassium, and the anions -- carbonate, bicarbonate, sulfate, chloride, nitrate, and fluoride. In addition, boron and silica concentrations are usually determined. These mineral constituents are expressed in parts per million (ppm). Other chemical and physical properties reported are the acidity of the water (expressed as hydrogen-ion concentration or pH), temperature, electrical conductance, total dissolved solids (TDS), total hardness, and percent sodium.

The mineral character of water is identified by determining the predominant cations and anions in equivalents per million (epm). Specifically, the name of an ion is used where its chemical equivalent constitutes one-half or more of the total ions for its appropriate group. Where no single ion meets this requirement, a hyphenated combination of the two most predominant ions is used and named in order of magnitude. For example, the character of a water in which calcium constitutes half or more of the total cations, and bicarbonates half or more of the total anions, is designated calcium bicarbonate. Where calcium constitutes less than half of the total cations with sodium next in abundance, and where bicarbonates are more than half the total anions, the designation of this water is calcium-sodium bicarbonate.

Irrigation

Because of diverse crop and soil conditions, it has not been possible to establish rigid limits for the quality of water used for irrigation purposes. Therefore, on the basis of mineral characteristics, irrigation water is commonly divided into three broad classes:

Class 1. Excellent to good - Regarded as safe and suitable for most plants under any condition of soil and climate.

Class 2. Good to injurious - Regarded as possibly harmful to certain crops under certain conditions of soil or climate, particularly in the higher ranges of this class.

Class 3. Injurious to unsatisfactory - Regarded as probably harmful to most crops and unsatisfactory for all but the most tolerant.

Tentative standards for irrigation water have taken into account four factors or constituents, as listed in Table 5.

TABLE 5

QUALITY CRITERIA FOR IRRIGATION WATER

Constituent	Class 1 Excellent to good	Class 2 Good to injurious	Class 3 Injurious to unsatisfactory
Conductance EC x 10^6 @ 25°C	less than 1,000	1,000 - 3,000	more than 3,000
Chloride, epm	less than 5	5 - 10	more than 10
Percent sodium	less than 60	60 - 75	more than 75
Boron, ppm	less than 0.5	0.5 - 2.0	more than 2.0

Municipal and Domestic

The most widely used criteria for determining the suitability of water for domestic and municipal use are the United States Public Health Service Drinking Water Standards. Limits for mineral and other constituents in water are divided into two groups: (1) concentrations which constitute grounds for rejection of the supply; and (2) recommended maximum concentrations. The current (1962) United States Public Health Service Drinking Water Standards are shown in Table 6.

TABLE 6

UNITED STATES PUBLIC HEALTH SERVICE
DRINKING WATER STANDARDS (1962)

Dissolved constituents	Concentration which constitutes grounds for rejection, in ppm	Recommended maximum concentration, in ppm
Arsenic (As)	0.05	0.01
Barium (Ba)	1.0	
Cadmium (Cd)	0.01	
Chromium (Hexavalent) (Cr^{+6})	0.05	
Cyanide (CN)	0.2	0.01
Lead (Pb)	0.05	
Selenium (Se)	0.01	
Silver (Ag)	0.05	
Alkyl benzene sulfonate (ABS) detergent		0.5
Chloride (Cl)		250
Copper (Cu)		1.0
Iron (Fe)		0.3
Manganese (Mn)		0.05
Nitrate (NO_3)		45
Phenols		0.001
Sulphate (SO_4)		250
Zinc (Zn)		5
Total dissolved solids (TDS)		500*

*Previous U. S. Public Health Service maximum permissible limit for total dissolved solids was 1,000 ppm, and the State of California Department of Public Health issues temporary permits for public water supplies under certain conditions when the concentrations of total dissolved solids is no greater than 1,500 ppm.

Maximum safe limits of fluoride ion concentrations are related to mean annual temperature and are defined by the State Department of Public Health as follows:

Mean annual temperature	Mean monthly fluoride ion concentration, in ppm
50° F	1.5
60° F	1.0
70° F - above	0.7

For temperature values between those shown in the table, the fluoride ion concentrations may be obtained by interpolation.

Total hardness is a significant factor in the determination of the suitability of water for domestic or municipal use. Waters containing 100 ppm or less of hardness (as $CaCO_3$) are considered "soft"; those containing 101 to 200 ppm are considered "moderately hard"; and those with more than 200 ppm are considered "very hard".

Water Quality in Major Aquifers

Ground waters extracted from the aquifers in the Santa Ana Gap area exhibit a wide range in chemical character and salinity concentration. For purposes of mineral quality considerations, three principal confined bodies of water were distinguished in the area. They occupy in upward succession (1) deposits of early Pleistocene age which contain the Main, Rho, and Omicron aquifers; (2) deposits of late Pleistocene age which contain the Lambda, Beta, and Alpha aquifers; and (3) the lower division of the alluvial deposits of Recent age which contain the Talbert aquifer. These bodies of water constitute the sources for substantially all the ground water withdrawn in the area. Representative analyses of ground water within Santa Ana Gap and under the adjoining Huntington Beach and Newport Mesas are listed in Appendix D, "Mineral Analyses of Ground Water, Anaheim Basin, Santa Ana Gap".

Two other distinct bodies of water are known to exist in the area. They are: a body of semiperched water that occurs in the upper part of the deposits of Recent age; and a body of fresh water which occurs in rocks of Tertiary age.

No domestic or irrigation well is known to be solely perforated in the semiperched zone in Santa Ana Gap. However, one partial water analysis from exploratory well 6S/11W-7Q5 indicates that the "semiperched" water in that location is of sodium bicarbonate character with 64 ppm chloride content.

No water wells are known to tap rocks of Tertiary age in the area of investigation. Information derived largely from oil well electric logs suggests that locally, the "Pico" aquifer (Tertiary age) contains ground waters which are essentially of good quality.

Lower Pleistocene Deposits -- Main, Rho, and Omicron Aquifers

A small quantity of ground water is extracted from the lower Pleistocene deposits within the Santa Ana Gap area of study. Analyses of water withdrawn from irrigation wells 6S/10W-6B3, -6K2, and Department test wells 6S/10W-5K2, -6N2, -7E2, and 6S/11W-1J4 are shown in Appendix D. These wells produce water which appears to be of undeteriorated native quality from the Main aquifer beneath the central portion of the Santa Ana Gap. These waters range from 200-400 ppm total dissolved solids, and are of sodium bicarbonate character with very low sulfate concentration.

Total hardness ranges from about 20 to 60 ppm. The waters are suitable for domestic and municipal purposes, but range from Class 2 to Class 3 for irrigational purposes because of their high sodium content.

Occurrences of native poor quality water have been noted in the Main aquifer (lower Pleistocene marine deposits) in the eastern part of the gap, and beneath the central and southern portions of Newport Mesa. These waters are probably of partial connate or postnate origin. Analyses from wells 6S/10W-9M3 and -17M2 are typical of these native poor quality waters. They are sodium chloride in character with concentrations ranging between 850 and 6,000 ppm total dissolved solids, and generally contain high bicarbonate and boron, and low sulfate concentrations. In addition, these waters appear to contain small quantities of carbonaceous material as indicated by their amber color; hydrogen sulfide odor is commonly noted. The presence of hydrogen sulfide -- accompanying a decrease in sulfate content and corresponding probable increase in bicarbonate in the water -- suggests the reduction of sulfate by bacteria in the presence of organic matter.

The few chemical analyses available from one irrigation well (5S/10W-33D1) and one test well (6S/10W-7E3) indicate that the Rho aquifer contains water similar in character to water extracted from the Main aquifer.

No analyses of ground water are available from the few wells which tap solely the Omicron aquifer of early Pleistocene age. However, based on a water analysis from a well perforated in both the Omicron and Rho aquifers, the waters of these aquifers appear to be very similar in chemical character and quality to those contained within the Main aquifer.

Based primarily on oil well electric logs, poor quality waters currently exist continuously along the coast within the lower Pleistocene deposits between the ocean and the North Branch of the Newport-Inglewood fault. Between the North Branch of the Newport-Inglewood fault and the Indianapolis fault, the waters are intermediate in quality; northward of the Indianapolis fault, the waters are essentially fresh.

Upper Pleistocene Deposits -- Lambda, Beta, and Alpha Aquifers

Ground water production from the upper Pleistocene deposits is significant, but is limited to the northern portion of Santa Ana Gap and Huntington Beach Mesa. Mineral analyses of the ground water from these upper Pleistocene deposits indicate that, although high in chloride and sulfate concentrations, it is similar in character to that in lower Pleistocene deposits. In general, these waters in the northern part of the gap appear undeteriorated in quality, and range in character from sodium bicarbonate to calcium bicarbonate with a total dissolved solids content of about 250 ppm. Total hardness ranges from 50 to 150 ppm. The waters are suitable for domestic and municipal purposes, but range from Class 2 to Class 3 because of high chloride content. Analyses of waters from wells 6S/10W-6J2, 5S/10W-30L5, and 5S/10W-29E2, which tap the Lambda, Beta, and Alpha aquifers, respectively, are presented in Appendix D. These upper Pleistocene aquifers are hydraulically continuous with the overlying Talbert aquifer in a number of areas of the Santa Ana Gap, as shown on Plate 10, "Areas of Hydraulic Continuity Between Aquifers".

Available water quality data from the upper Pleistocene aquifers on Huntington Beach Mesa suggest that impairment has developed over a period of years. This degradation is shown by the analyses of water from wells

HUNTINGTON BEACH OIL FIELD, 1939, LOOKING EAST TOWARD SANTA ANA GAP

Spence Air Photos

Oil field brines discharged on the surface of Huntington Beach Mesa are thought to have moved downward and laterally to the east under a favorable hydraulic gradient.

6S/11W-1D2 and -1F2 where the ground waters are of calcium chloride character and exhibit relatively high total dissolved solids (2,500 ppm). The occurrence of degraded ground waters within the upper Pleistocene aquifers since about 1925, before the landward hydraulic gradient was evidenced, is thought to be in large part the result of improper disposal of oil-field brines derived from the Huntington Beach oil field. Areas of poor quality water underlying Huntington Beach and Newport Mesas are depicted on Plate 14.

In 1958, the ground water level gradient in the upper Pleistocene aquifers was conducive to the migration of degraded waters from Huntington Beach Mesa eastward into the gap. In addition, movement of waters from the mesa into the Talbert aquifer prior to 1950 was suggested by the distinct landward bulge in high chloride waters, which occurred in Section 1, T6S, R11W, just prior to that year. However, by 1963 the hydraulic gradient had been reversed and water from the Talbert aquifer was moving into the Alpha aquifer beneath Huntington Beach Mesa.

Although the water-bearing zones of both early and late Pleistocene age yield waters of somewhat similar character, a natural softening gradation occurs with depth; that is, the proportion of sodium among the cations increases with depth at the expense of calcium.

Recent Deposits -- Talbert Aquifer

The Talbert aquifer, which occupies the lower division of the alluvial deposits of Recent age, functions as a ground water conduit which extends uninterrupted from the coast inland to the forebay of the Anaheim Basin. Because water in the aquifer is rather effectively confined, and is at relatively shallow depth, it has sustained a large part of the withdrawals for irrigation and other rural uses in the gap.

Native waters extracted from the Talbert aquifer in the area were historically of excellent mineral quality. Analyses of water extracted north of the saline intrusion front in this aquifer during 1963 exhibited a continuance of this excellent mineral quality. The analyses of water from wells 5S/10W-30L6, -30N4, and -30P5 are considered to be representative and are presented in Appendix D. These native good quality waters range from calcium bicarbonate character with total dissolved solids from 250 to 500 ppm to sodium-calcium bicarbonate character with about 250 ppm total dissolved solids. Total hardness ranges from 150 to 375 ppm. The native calcium bicarbonate water is prevalent in the northern part of the gap, whereas the native sodium-calcium bicarbonate water is confined to an area within 2-1/2 miles of the coast. These native waters are suitable for domestic and municipal uses, and range from Class 1 to Class 3 for irrigation uses.

Native saline waters with total dissolved solids content as high as 6,250 ppm have been known to occur in the eastern part of the area immediately to the east of the Santa Ana River, and south from Adams Avenue to the coast, and also locally west of the Santa Ana River, and south of Hamilton Street. The occurrence of these native saline waters may have been the result of the blending of upwelling connate and postnate waters from the underlying Pleistocene aquifers.

Wells which extract water seaward of the saline water front have exhibited yearly increases in chloride ion and total dissolved solids concentrations. This is clearly indicated in Plate 14 by the 50 ppm isochlor for the years 1931, 1944, 1950, 1958, and 1963. The major source of this degradation in the Talbert aquifer is undoubtedly water from the ocean, moving inland under the influence of a landward hydraulic gradient. Since native good quality Talbert waters generally contain chloride concentrations ranging from 15 to 30 ppm, the area of recognizable degradation is considered to extend from the 50 parts per million chloride ion contour, seaward to the coast. In 1963, this area encompassed about 6,500 acres as is shown on Plate 14.

Chloride ion concentrations in excess of 5,000 ppm occur in the southern portion of the Talbert aquifer as indicated on Plate 14. These highly degraded waters occur seaward of a parabolic nose with an axis about midway between Newland and Cannery Streets. The axis probably describes the most favorable path of high chloride waters moving inland from the ocean.

Although intruded, the uppermost part of the Talbert water-bearing zone contains fresh water within 1 mile of the coast because of the nature of the saline wedge. Conductivity traverses of the water in the Department's test wells 6S/10W-6N2 and 6S/11W-1Q2 indicate that there is a definite vertical change in salinity in the Talbert aquifer with the most highly degraded waters near its base. This vertical change in salinity was further substantiated by electric log data.

As previously noted, hydraulic continuity exists between the Talbert aquifer and the underlying and adjacent upper Pleistocene aquifers. Degraded water from the Talbert aquifer can readily pass into steeply dipping Pleistocene deposits in the northern part of the gap.

Available information indicates the major source of water quality degradation in the Talbert aquifer is the intrusion of sea water, although in localized areas the character of the degraded waters is highly indicative of a number of other sources of degradation, such as improperly discharged oil-field brines, and upwelling connate and postnate waters from underlying aquifers.

CHAPTER VI. CONTROL OF SALINE INTRUSION

Previous chapters of this report describe the geologic features in Santa Ana Gap and the historic hydrologic conditions which have permitted sea-water intrusion to extend some 4 miles inland from the coast. Also discussed were the historic fluctuations in ground water levels and the anticipated use of ground water in storage in the years when available imported supplies dwindle. Under the assumed basin management, levels would vary moderately between winter and summer and extensively between a series of wet and dry years. The lowering of levels in the summer months and during extended droughts would provide storage capacity to accommodate natural and artificial recharge.

Considering these probable conditions, a feasible plan to control saline invasion into these aquifers should be formulated and implemented. The chief purpose of this chapter is to describe briefly the general methods of salinity control. Also discussed will be the economic and legal implications pertinent to a choice of a particular salinity control method.

General Salinity Control Methods

There are five basic salinity control methods which can be used to prevent further sea-water intrusion and to repel sea water from areas already affected by intrusion. Four of these methods constitute dynamic systems which would demand continued and possibly significant operational and maintenance expense. The fifth method is a static type which would require only the expense of periodic monitoring. A sixth method described is a combination of two basic methods. These six methods are designated as follows: Reduction of Ground Water Extractions, Artificial Recharge (Spreading Basins), Injection Ridge, Pumping Trough, Combination Pumping Trough and Injection Ridge, and Static Barrier.

Reduction of Ground Water Extractions

Basically, this method consists of reducing ground water extractions to allow water levels to be restored to elevations at or just above sea level and of maintaining those elevations except for short periods of peak demand. The restoration and maintenance of water levels to such elevations within a basin suffering a large cumulative water supply deficiency would require the importation of large amounts of supplemental water for direct use, and the reservation of all the natural supply for basin replenishment. This method does not, by its very nature, permit full utilization of the ground water basin storage capacity.

A correlative method consists of rearranging the pumping pattern. If the area of major extractions were moved inland from the coastal portion of the basin, the pumping trough would also move inland. If the trough were below sea level, intrusion would continue. However, the oceanward side of the pumping trough would assume a flatter landward gradient, slowing the movement of ocean water. At the same time, the landward side of the pumping trough would assume a steeper seaward gradient, increasing in many cases the subsurface inflow of fresh water from inland areas. These modified gradients would serve to retard somewhat the further incursion of sea water.

Artificial Recharge (Spreading Basins)

The introduction of large volumes of local or imported water into the depleted basin by spreading in the basin forebay can raise ground water levels to elevations above sea level. This would effectively repel sea-water intrusion in the Santa Ana Gap. However, although it is an effective measure, basin recharge by surface spreading can only be practiced if the source of water and the aquifer transmission characteristics are sufficient to maintain ground water pressure levels above sea level along the coast. As noted previously, recharging in the forebay has proved effective in controlling pressure levels in Santa Ana Gap, although in the future large quantities of water for this purpose cannot be assured. In addition, under basin management techniques, the ground water basin would probably be operated at levels somewhat lower than sea level.

Injection Ridge

An injection ridge method would require creation and maintenance of a fresh water injection ridge in the water-bearing deposits near the coast. To produce a seaward gradient between the barrier and the ocean, the injection head of this ridge should be maintained above sea level. In areas where ground water occurs under artesian conditions, the injection ridge could be maintained by water injected through wells. Where nonpressure conditions obtain, a free ground water ridge could be created by surface spreading.

An injection ridge would create the desired seaward hydraulic gradient across Santa Ana Gap. This ridge would be just as effective in repelling sea-water intrusion as would a seaward hydraulic gradient extending the entire distance from the forebay to the ocean. An advantage is that water levels inland from the injection ridge could be lowered below sea level to permit the use of a greater amount of underground storage capacity, and at the same time, water that would otherwise be wasted after the basin fills could be salvaged. Most of the water used to maintain the injection ridge would flow landward into the basin and consequently could be recovered. The small portion of the water injected that would move toward the ocean under the influence of the seaward hydraulic gradient would be lost. Imported water or effluent from a tertiary sewage treatment process might be used as a source of water for this type of barrier.

Operation of an injection barrier presents certain problems. Perhaps the most serious difficulty is that because of the very nature of the method, it requires the maintenance of piezometric heads above sea level along the injection alignment; these heads may also exceed ground surface elevations. This condition could cause waterlogging in the vicinity of the injection wells. Experience has also shown that frequent well rehabilitation is necessary to maintain required injection rates at minimum heads.

Pumping Trough

A pumping trough can also be an effective barrier against sea-water intrusion if it is created along the coast and if levels are maintained below the lowest water level in the basin. This condition then forms the desired seaward hydraulic gradient over the major portion of the basin. Under the influence of the resultant gradients, sea water would move a short distance from the ocean to the trough and fresh water would move from the basin seaward toward the coastal trough. Water extracted from the line of heavily pumped wells which create the trough would be wasted, unless a demand arose for the resultant brackish to saline water. Possible uses for this water include saline conversion, oil field secondary recovery operations, and powerplant cooling.

A serious disadvantage of a pumping trough must be considered in proposing its use in Santa Ana Gap. Because a pumping trough, to be effective as a barrier to saline intrusion, must be below the point of lowest piezometric elevations in the entire basin, it would tend to drain the shallow sediments in a large area in its immediate vicinity. This would not offer any special difficulty, if no organic soils existed in the area influenced by the pumping trough. However, as shown on Plate 4B, there are extensive deposits of peat and related organic materials in the Santa Ana Gap area. Normally, these soils are in a saturated condition. When peaty materials are dewatered as a result of lowering of the ground water levels, they first shrink and become compressed. Subsequently, a massive reduction in volume occurs as the materials oxidize. Because of this volume decrease, subsidence of the overlying surface occurs, even without surcharge.

Combination Pumping Trough and Injection Ridge

The use of combination of two methods discussed previously, a pumping trough and a fresh water injection ridge, was also considered as a barrier type. The pumping trough would be operated as the oceanward side of the barrier and the pressure ridge as the landward side. A combination barrier such as this would require about one-third as much extraction to achieve the same effect as a pumping trough alone, and would require injection of slightly smaller total quantities of fresh water to achieve the same effect as a pressure ridge alone, if barrier level conditions were optimized.

The major advantage of a combination ridge and trough barrier would be that the undesirable side effects of each by itself, such as waterlogging and subsidence, could be greatly reduced through proper operation. The importance of these side effects in this urban-agricultural area is a matter of paramount concern.

Static Barrier

A static barrier method would involve the construction of a subsurface barrier, similar to a positive cutoff structure through permeable materials beneath a dam. The purpose of this subsurface barrier would be to reduce the permeability of the water-bearing materials and thereby preclude subsurface inflow of sea water. (Subsurface outflow of fresh water would also be precluded.) On the landward side of the barrier, pressure levels could be drawn down below sea level by an amount limited only by the effectiveness of the barrier.

A barrier of reduced permeability could be achieved in several ways, among which are steel piling, puddled clay, cement grout, or chemical grout. If constructed from these materials, the barrier would probably be permanent and would demand little or no maintenance.

A major problem in evaluation of a static barrier in the Santa Ana Gap is that it involves many unknown factors. A barrier of this type and magnitude has never been constructed; experience has been limited to cutoff walls up to 60 feet deep below dams and up to 45 feet deep beneath levees along the Columbia River and at San Pedro in Los Angeles County, respectively. None of these has extended to the depth (90 to 230 feet) required for a sea-water intrusion barrier in the gap. Unknown quantities include feasibility of construction, life of the barrier under constant exposure to sea water, capacity of the barrier to withstand a high differential head, and the possible effects of tectonic disturbances on the barrier. In addition to these unanswered questions, construction of a static barrier would do nothing to alleviate side effects caused by partial dewatering of the basin, such as subsidence. Depending upon the level at which the basin was operated, it might become necessary to augment a static barrier with some injection facilities in order to preclude subsidence.

Existing and Planned Barriers

An injection-type barrier approximately 1 mile long, financed by the State, was constructed in the mid-1950's as an experimental barrier project along Santa Monica Bay by the Los Angeles County Flood Control District. The Flood Control District is now extending this proven barrier along the bay from the Palos Verdes Hills to Ballona Gap. The Los Angeles County Flood Control District and the Orange County Water District are also constructing another barrier in Alamitos Gap east of the City of Long Beach. That sea-water intrusion barrier will consist of an alignment of injection wells supplemented by a small network of extraction wells located seaward of the injection alignment.

In addition to the study reported here, the Department of Water Resources began a study in November 1964 (also under the Porter-Dolwig Ground Water Basin Protection Law), on the feasibility of protecting the remaining coastal area of Anaheim Basin from sea-water intrusion. The study area is in the vicinity of Bolsa Gap and Sunset Beach, which lie between Santa Ana Gap and Alamitos Gap.

Economic Considerations

The principal economic effects on an area where the ground water basin is subjected to sea-water intrusion are the impairment of the ground water basin as an underground storage reservoir, the degradation of the potable water stored in it, and the loss of its value as a fresh-water distribution system. Each of these functions, which can be impaired or completely destroyed by salt-water intrusion, has tremendous economic value in a large basin such as Anaheim Basin.

The absence of precipitation during the summer months reinforces the seasonal variation in the demand for water. Furthermore, average annual precipitation is not only modest, but also highly variable. Dry years often come in succession for a decade or more. Thus, ground water basins have functioned as natural regulators of runoff and as storage reservoirs for daily and seasonal peaking requirements. These requirements must be met either from surface storage facilities or from ground water basins.

Standby pump and well capacity is much more economical to develop and maintain than surface storage and distribution facilities. When the additional sizing costs necessary to meet peaking requirements in surface distribution facilities are considered, the critical economic importance of ground water basins for peaking purposes in Southern California becomes apparent. In the future, water producers will require substantial peaking capacities, possibly equivalent to as much as 15 percent of their total annual demands. If ground water storage is not continuously available for peaking purposes, alternative surface facilities would be required. These facilities would represent a cost conservatively estimated at hundreds of millions of dollars based on the present value of land and construction entailed. Of course, this presupposes that there are not alternative ground water basins available for the same purpose. While there may be excess capacity for peaking purposes in Southern California at the present time, as water utilization increases, storage capacity will become smaller in relation to annual use. Furthermore, were Anaheim Basin to be degraded by saline intrusion, the use of either supplementary surface storage, or another ground water basin for peaking purposes, would involve a large capital investment to provide for the necessary additional peaking capacity and expansion of the distribution system.

The Los Angeles County Flood Control District has reported that construction of tank storage in its service area costs approximately $16,300 per acre-foot of capacity*. For large volume surface storage, a more reasonable solution would be the use of earthfill dam reservoirs. Storage facilities of this type to meet the peaking needs of Anaheim Basin can be conservatively estimated to cost $250 per acre-foot.

Ground water basins also serve as water distribution systems. That is, water entering the basin through natural or artificial recharge may be extracted in a wide area overlying the basin. It is often possible to spread imported water at one location, or at a limited number of areas, and use the aquifers as a distribution system. Prior to initiation of planned operations of this type, much of the capital investment may have already been made in wells and pumping facilities. Anaheim Basin has functioned as an effective distribution system for both natural runoff and spreading of imported water. The abandonment of the capital investment in wells and pumping facilities, and the very large cost of a

*Los Angeles County Flood Control District, "Report on Required Facilities for Replenishing and Protecting Ground Water Reserves in the Central and West Cost Ground Water Basins, Part I" (pp. 97-101).

comprehensive surface distribution system which would be needed should the basin's capacity to function as a distribution system be destroyed by saline degradation, would represent a very substantial economic loss indeed.

Consequences of Inaction

As a basin becomes degraded by the intrusion of sea water, more and more wells are abandoned. Agricultural interests dependent on such wells must develop new sources of supply, revert to dry farming, or discontinue operations in the intruded area. Urban areas using ground water find their well fields pumping saline water, and they must be relocated or abandoned. Either course represents a serious economic loss. Relocation of facilities also involves additional expenditures for expansion of the surface distribution system. Ultimately, if no action is taken, the utility of the basin for storage is lost, as is the ground water stored therein. Even a series of "wet" years and a full basin might not completely remove the saline water or entirely restore the basin to full usefulness. The agricultural economic activity of the area could be greatly curtailed or disappear completely.

In evaluating the economics occurring from the operations of barrier systems along the coastline of Orange County, it is necessary also to evaluate the economic situation of operating the ground water basins in Orange County without barrier systems in order to make an evaluation of the relative economics of the two alternatives. The following paragraphs explain economic factors pertaining to the situation if no barriers to sea-water intrusion are installed along the coastline of Orange County.

Considering two sources of water supply, that is, local ground water supply and imported water from various sources, the ground water supply will generally be cheaper than the imported water supply, because of the development and transmission costs of imported supplies. Economics of the situation are such that the cheaper ground water will be used rather than the more expensive imported water. This preferential use of ground water has been the case historically in which the local supply is used to its limit, generally for agricultural uses which are more sensitive to the cost of water than are municipal and industrial water uses. In the past, in Anaheim Basin, ground water has been used in excess of the approximately 125,000 acre-feet per year natural supply to the basin, thereby causing a condition of overdraft which is illustrated by the sustained lowering in ground water levels in the basin and the necessity of purchasing imported water for recharging purposes. It is anticipated that demand in excess of supply will recur in the future and, with lowered elevation of the ground water surface in the basin, the rate of saline intrusion will be accelerated.

Without barriers to saline intrusion, the salt waters would continue to invade into the aquifers and advance steadily to the north and northeast toward the ground water trough. The trough itself would retreat inland ahead of the advancing saline front, because of the progressive abandonment of wells. The result would be a decrease in available ground water storage capacity because of the salinity problems in the intruded portion of the aquifer. Additional results include an increase in costs of drilling new wells to supply water for areas overlying the ground water basin which has become intruded with sea water, and an eventual decrease in the area available for fresh water recharge. These increased costs of hundreds of thousands of acre-feet are detriments to operation of the basin without adequate salinity barriers.

Costs to provide 45,000 acre-feet of peaking storage in alternative surface reservoirs can be conservatively estimated to be in excess of 10 million dollars for the present annual demand of 300,000 acre-feet. This value can be considered a benefit to basins operated with salinity barriers, since it would be a necessary cost to basin operation without barriers.

Natural runoff which percolates into the ground water basin loses economic value if it flows into a basin which is heavily degraded by saline water. If Anaheim Basin were degraded to such an extent that the total average safe yield of approximately 125,000 acre-feet per year could not be developed, the economic loss of this water, conservatively evaluated at $15 per acre-foot, would amount to $1,875,000 per year. The present worth of such a yearly loss over a 50-year period, assuming a very conservative 4 percent compound interest rate, would amount to over 40 million dollars.

Without barriers, saline intrusion into Anaheim Basin would, over a period of time, degrade much of the remaining fresh water stored in the entire basin. This could well amount to millions of acre-feet of fresh water, representing an economic value in the tens of millions of dollars.

Although a dollar value cannot readily be assigned to it, the value of the ground water basin for an emergency water supply and distribution system constitutes an important justification for protection works. If the surface distribution system should become unusable because of natural or man-made emergency, or the imported supply interrupted, reduced, or contaminated, ground water could eliminate tremendous economic loss, or even assure survival itself. In addition, underground supplies would not, in the short run, be affected by bombing or fallout.

It is not possible at this time to project the speed or extent of degradation over the entire basin under various conditions of extraction because geologic and hydrologic data for the Anaheim Basin are, as yet, incomplete. For this reason, it is not possible to assign a dollar value, per se, to the various economic losses which would take place without some action to prevent sea-water intrusion. However, effects which may result from taking no corrective action, as well as the effects of limiting extractions to "safe yield", may be discussed without specific dollar value determinations.

<u>Limiting Ground Water Use to Natural Supply</u>

If no cumulative water supply deficiency existed, a plan of limiting ground water use to natural supply would maintain ground water levels at a point which would check sea-water intrusion. Although there would be no need to abandon wells, this severe restriction placed on local water use in the basin would require substantial increases in importation of more costly waters, and could severely curtail the considerable agricultural development still present in Orange County. It would mean abandoning the economic value of millions of acre-feet of water still in storage. While extractions cannot permanently exceed safe yield, the existence of considerable quantities of water in ground water storage allows the postponement of safe yield operation. This can be of great economic value. For example, if it is assumed that ground water costs $10 less than alternative imported supplies available to Orange County*, and a million acre-feet of ground water were used, the ground water use would result in a present worth saving of more than $8,000,000 at a 4-percent compound interest rate, even if the water were replaced at the higher cost 50 years later. At a compound interest rate of 5 percent, the saving would amount to more than $9,000,000.

A safe yield operation prior to 1972 would probably be unrealistic. Continued growth in Orange County, coupled with a decreasing availability of Colorado River water to the County, will require extractions from Anaheim Basin which will exceed natural and artificial replenishment in the years before water from the State Water Project is delivered to Southern California. The yearly deficiency of local supply is expected to reach an annual total in excess of 100,000 acre-feet in the years just before water from Northern California becomes available.

Optimum Ground Water Use with a Barrier

The principal economic benefit of a salinity barrier comes from protecting the value of the water in storage in the basin and the water supply continually replenishing it. If protected from intrusion, this water supply would continue to be fully available for use in the basin.

To areas dependent upon a large continual supply of imported water, particularly where the total water demand fluctuates widely, the utility of the ground water basin for regulatory storage represents an important justification for protection. If Anaheim Basin could be operated

*A very conservative assumption because the cost of pumping ground water would average less than $10 per acre-foot. Another $10-cost per acre-foot may be assumed as a pumping assessment for barrier construction and maintenance.

with barriers to saline intrusion (note that barrier requirements include not only salinity barriers in Santa Ana Gap but also in Bolsa, Sunset Beach, and Alamitos Gaps), then the ground water basin could be used without the threat of saline intrusion and its inherent costs. However, the cost of installation and operation of sea-water intrusion barriers would be incurred. With the ground water basin managed under an assumed plan of operation, ground water elevations within Anaheim Basin might be drawn down 100 or more feet below sea level within the inland parts of the basin. Operation of these ground water elevations would provide large capacity for the storage of inflowing surface water during periods of above-normal precipitation. The benefits of operating the ground water basin with barriers to sea-water intrusion along the coastline are that the entire 125,000 acre-feet annual recharge to the ground water basin would be fully and continuously usable. The ground water basin could thus be operated to provide the required capacity without degradation. The savings derived from making possible a smaller distribution facility because of use of the ground water basin for peaking purposes would further offset the cost of constructing a barrier.

The value of maintaining a ground water basin solely for an emergency water supply might constitute an important justification for protection works. The value of such an emergency supply would be enormous during a period of extended drought, or during times when the surface distribution system was not usable because of emergency or maintenance shutdowns or enemy action during war. The value would increase with the severity and duration of the emergency.

Legal Considerations

Several legal considerations are involved in implementation of any proposal to prevent sea-water intrusion. Examples of such considerations are the requisite authority and power to take appropriate action. Others include the effects of these actions on the property owners in the area.

Authority to Control Sea-Water Intrusion

At present, there is no single public agency empowered to accomplish the actions necessary to prevent and control sea-water intrusion by all the methods presented in this chapter. Effective control of intrusion will involve more than just spreading waters or constructing and operating a barrier; it will also entail planned use and management of the entire basin. This may include water spreading, limiting ground water extractions, and rearranging pumping patterns.

Existing law is not completely adapted to the implementation of a multiple-method saline intrusion control program. For example, no state agency or local district has the authority to enforce a reduction of pumping or rearrangement of pumping patterns, except under a voluntary agreement among the affected parties or after a ground water adjudication. A reduction of pumping may be effected indirectly by the levying of assessments or charges based upon the amount of ground water extracted; in some cases substitution of water supply may be used to reduce pumpage in desired areas. Voluntary agreement among the affected parties or court order is usually required, however, to accomplish substantial reduction in pumping and probably in all instances to bring about a rearrangement of pumping patterns.

In actions to determine rights to waters of underground basins in Santa Barbara, Ventura, Orange, San Diego, and Los Angeles Counties in which it is acting as court referee, the State Water Rights Board is authorized to initiate steps to halt serious sea-water intrusion. After it has filed its report as referee, the Board may apply to the referring court for a temporary injunction to halt or reduce pumping, "if it appears that underground water is being pumped in an amount which, if not restricted, would destroy or irreparably injure the waters of the basin due to ocean water intrusion before final judgment can be had" (Water Code Section 2020). Where such a preliminary injunction has been granted, the final judgment must "equitably compensate in quantities of water for such variations as there may be between the rights of the parties to the use of water on which such preliminary injunction is based, and as such rights are determined in such final judgment" (Water Code Section 2021).

Not all public agencies have authority to raise and expend funds for saline-intrusion prevention projects. The Orange County Water District does have such authority under its organic act*. It may raise funds for such purposes by the levy of limited general assessments against all taxable property in the District, excluding personal property (Section 17); and, if approved by two-thirds of the votes cast at an election on the proposition (Section 21.7), by incurring a bonded indebtedness (Section 21). Such funds may be used for the purpose of:

"(a) acquiring, constructing or developing intrusion prevention projects, spreading grounds or basins, waste water reclamation and water salvage projects, canals, conduits, pipelines, wells,

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*Orange County Water District Act, California Statutes 1933, Chapter 924, page 2400, as amended.

or other works useful or necessary for the purposes of the district and to carry out the provisions of (the Orange County Water District Act); and

"(b) acquiring any real or personel property or rights or privileges therein useful or necessary for the foregoing projects or works or for the purposes of the district ..." (Sections 17 and 21).

Water Rights

Rights to extract ground water are property rights, and their owners may be entitled to compensation if the rights are taken or damaged. A saline-intrusion barrier could affect water rights in a number of ways. For example, operation of an injection ridge might accelerate the movement of the toe of the saline wedge into an area formerly underlain by fresh water. Also, lowering of ground water levels as part of basin management made possible by a salinity barrier could withdraw the supply from shallow well owners.

Water rights might be used as a basis for distribution of costs of a saline-intrusion control program, for furnishing water to those who are entitled to it, and for payments of damages to those whose water rights may be affected adversely.

Possible Property Damages from a Sea-Water Intrusion Barrier

In addition to damages described in the foregoing sections, the operation of a salinity barrier could cause direct damages to real property. A fresh-water injection ridge would raise water levels in the vicinity of the ridge with possible waterlogging of the ground so as to impede drainage of the area. A pumping trough, on the other hand, would lower water levels, possibly dewatering certain soils that might consolidate so as to cause subsidence.

CHAPTER VII. SALINITY BARRIERS IN SANTA ANA GAP

The purposes of this study were to determine the factors which control the intrusion of sea water into the water-bearing deposits of Santa Ana Gap, and to formulate general plans for the construction of facilities to prevent this intrusion. The design of any remedial facility is based upon physical conditions which prevail in the subject area. These factors include geologic, hydrologic, and water quality conditions, and the waterlogging and subsidence characteristics of local peat soils. The salient aspects of each are summarized in this chapter. Location, description, and advantages and disadvantages of the most feasible types of barriers, as well as approaches to the minimization of undesirable side effects, are also discussed in this chapter.

Geologic Features

As a result of an extensive exploratory drilling program, the geologic framework of the Santa Ana Gap area was delineated in detail. Several aspects of the geologic setting were found to have very significant effects upon the history of sea-water intrusion in the area. In addition, these aspects control not only the future paths of saline intrusion, but also any remedial activity which might be envisioned.

The important fresh-water aquifers in the Santa Ana Gap area are sands and sandy gravels of early and late Pleistocene, and Recent ages. Eight major aquifers were delineated: the Main, upper and lower Rho, and Omicron of early Pleistocene age, the Lambda, Beta, and Alpha of late Pleistocene age, and the Talbert of Recent age. With the exception of the Talbert aquifer, these water-bearing zones have been faulted and folded across the parallel faults of the Newport-Inglewood system and the semi-parallel faults of the Santa Ana River system.

Erosion and continued structural activity in mid-Pleistocene time resulted in an unconformable relationship between lower and upper Pleistocene strata. The major significance of this unconformity is the mergence of the upper Rho and Omicron aquifers where their eroded flanks encounter the overlying beds of the Lambda aquifer.

Near the end of Pleistocene time, folding continued and downcutting along the Santa Ana River produced the ancient Santa Ana Valley or Gap. This erosion locally exposed the upfolded edges of the upper Pleistocene Lambda, Beta, and Alpha aquifers in the bottom and sides of the old valley.

At the beginning of Recent time, coarse aquifer deposits were laid down over the partially exposed Pleistocene aquifers. The ancient gap was thus partially backfilled, first with the coarse debris called the Talbert aquifer, and later with finer sediments which now constitute the surface of the gap. The Talbert aquifer was deposited continuously by the Santa Ana River from the forebay area across Anaheim Basin. It extends uninterrupted through Santa Ana Gap and across the major structural systems to the sea.

This sequence of sedimentary and structural events has produced a relatively complete natural barrier in the lower Pleistocene sediments along the main Newport-Inglewood structure. However, the Recent age Talbert aquifer extends as a permeable tongue across this and other structures through Santa Ana Gap to the ocean. Generally, north of Adams Avenue, the base of the Talbert aquifer intersects the eroded flanks of previously upwarped Pleistocene aquifers; along the sides of the mesas the Alpha and Beta aquifers are encountered. Thus, under favorable hydraulic heads, the structural framework allows saline waters to enter the Talbert aquifer from the ocean floor and extend inland across the main structural barriers. From there the saline waters can move laterally into the upper Pleistocene aquifers underlying the mesas, and downward into the upper and lower Pleistocene aquifers beneath the gap.

Hydrologic and Water Quality Features

The geologic framework of the Santa Ana Gap area provides ready conduits for the invasion of saline waters into the ground water basin. However, the conditions of ground water hydrology at any point in time dictate the conditions within those conduits. Since the mid-1920's, hydrologic conditions have been intermittently favorable for saline intrusion because piezometric elevations lower than sea level provide a favorable landward hydraulic gradient. By the end of 1961, saline waters had advanced a maximum of 4 miles inland from the coast under the influence of these gradients and had entered a number of aquifer units, including the Talbert, Alpha, Beta, and Lambda aquifers.

Conditions of ground water deficiency which had caused the decline in ground water levels were considered during the investigation. It was determined that ground water supply conditions in early 1945 would constitute a convenient "storage reference point". It was also determined from available supply and demand data that by the fall of 1956 the ground water basin had sustained its maximum historic cumulative deficiency. This accumulated deficiency resulted in mean annual piezometric levels of approximately 22 feet below sea level, 2 miles north of Warner Avenue, or in the vicinity of Bolsa Avenue during 1957. Subsequent to 1957, artificial recharge to the ground water basin from spreading operations of the Orange County Water District began to reduce significantly the net deficiency, and ground water levels in Anaheim Basin rose accordingly.

Historic water demands and local and imported supplies were considered and generally compared with historic ground water level fluctuations near Bolsa Avenue. It was concluded that, with the assumed planned basin management, levels near Bolsa Avenue might decline to elevations of about 30 feet below sea level under probable conditions of future use and decreasing amounts of imported water available for spreading purposes. For the purpose of determining dynamic barrier water requirements under more extreme conditions, an assumed level of 50 feet below sea level at Bolsa Avenue was also used.

Salient ground water quality features of the study area include the position of the intruding saline wedge in the gap, and the location of impaired ground waters beneath the adjacent mesas. These waters are graphically delineated on Plate 14. The position of saline water is of considerable significance in the location, selection, and design of any salinity barrier, in order to preclude further movement of these waters into Anaheim Basin.

Subsidence and Waterlogging of Peat

Beds of peat and lenses of organic material occur within a large portion of the Santa Ana Gap area; south of Bolsa Avenue they underlie an area of at least 1,100 acres. These organic soils accumulated in and around fresh water springs and swamps which were commonplace in the gap prior to agricultural development about 1900. Because of prevailing anerobic conditions during and after burial, the peaty soils were protected from complete decomposition. When these materials are dewatered, they first shrink and become compressed. Subsequently, a massive reduction in volume occurs as the organic debris oxidizes. Because of this volume decrease, subsidence of the overlying surface occurs even without surcharge. Some areas within Santa Ana Gap have already experienced substantial subsidence, in some cases up to 20 feet, due to the effects of lowering the level of saturation in the peaty materials.

Because of their mode of origin peat soils are moderately permeable, and locally extend downward to the top of the Talbert aquifer. Pressure levels at or above the ground surface in Santa Ana Gap would result, therefore, in upward leakage through the organic materials and the historic springs and swamps would be locally reestablished.

The thickness and areal extent of peat and allied materials in the gap area are delineated on Plate 4B, "Location of Peat and Organic Soils". Knowledge of the nature of these materials is of primary significance in the location, selection, and design of barriers to the incursion of saline water in Santa Ana Gap.

Selection of Barrier Alignments

The selection of barrier alignments was based upon the physical parameters developed during geologic, hydrologic, and water quality evaluations. In addition, elevation and length of alternative alignments and undesirable side aspects were considered.

For the static or physical barrier and the extraction trough, four alternative alignments were initially chosen. These were selected to coincide as nearly as possible with locations where the base of the lowest aquifer subject to intrusion was at a relatively shallow depth, and areas where faults could be utilized as potential abutments. Peat deposits were avoided where possible. The alignment finally selected for both physical cutoff wall and extraction trough cost estimates is shown as Alignment No. 2 on Plate 12. It is possible that if the alignment were moved further to the south, a smaller quantity of peat soils might be encountered. However, a southerly alignment with a pumping trough operating alone as a barrier would have only negligible beneficial effects upon subsidence. In addition, the subsurface geologic conditions of alignments to the south are lithologically and structurally complex. Therefore, a more southerly alignment was not proposed.

For the injection ridge barrier, three alignments were initially chosen. As in the case of extraction alignments, it would be desirable to select areas of minimum thickness of affected aquifers. However, to avoid severing the intruded wedge of saline waters or causing the degraded mesa waters to move basinward, the injection alignment should be located on the landward side of known areas of saline ground waters. This feature precludes a location in the shallowest aquifers. Additional aspects governing location selection include length and land surface elevation. (The greater the land elevation, the less is the possibility of waterlogging of surface sediments adjacent to the injection wells.) Based upon these criteria, a single alignment was selected along Ellis and Talbert Avenues as shown on Plate 15. Note that if saline waters are driven significantly seaward during the next several years as a result of recharge operations in the forebay of Anaheim Basin, an alternative location might be considered for this alignment. For this purpose the alternatives A and B are delineated on Plate 15.

Comparison of Remedial Measures

A detailed comparison of the available remedial measures is presented in the following paragraphs. A discussion of a physical salinity barrier is presented first, followed by various dynamic barrier systems.

Static or Physical Barrier

Construction of a static, or physical, salinity barrier was considered along Alignment No. 2 (extraction), shown on Plate 15. A number of types of physical subsurface barriers or cutoff structures have been discussed in this report. However, the only type for which cost estimates were prepared was a puddled clay cutoff wall constructed by drilling large diameter holes and replacing the aquifer deposits with materials or mixtures of low permeability. Construction of a physical barrier was considered only along Alignment No. 2, because it traverses the area in which depths to the lowest zone subject to saline intrusion are at a minimum (90 to 230 feet below land surface).

The advantages of physical or static barrier construction in Santa Ana Gap include the minimal maintenance required in continued operation. Once it has been constructed, all that remains necessary to assure protection of the basin is periodic monitoring of both piezometric elevations and ground water quality on each side of the subsurface cutoff. Only one semiskilled employee would be required for this type of operation.

The disadvantages of the static barrier are numerous. They include the necessity of extracting degraded waters which would be trapped in aquifers landward of the barrier. Natural flushing of salts from the basin under conditions of a seaward gradient would never again be possible. Water levels between Bolsa Avenue and the static barrier would decline under conditions of planned utilization of the basin so that a relatively flat piezometric surface would exist from the barrier to Bolsa Avenue. These low levels would probably produce significant subsidence in the peat soils. Other disadvantages include lack of construction experience. A cutoff to depths locally in excess of 200 feet as required in Santa Ana Gap has not been built prior to the time of this report. In addition, there is a paucity of even experimental data on either ion or gross fluid permeability of this type of subsurface cutoff.

It is concluded that if a static barrier were installed, a relatively large portion of the ground water reservoir underlying Santa Ana Gap would be preserved from further saline intrusion. However, from the standpoint of engineering and costs, a static or physical barrier of the type considered is generally not feasible. This is because of the lack of experimental data and construction experience, plus the problems of counteracting other adverse results, such as removal of entrapped saline waters and the effects on peat soils. An estimate of the cost of utilizing this method is presented in Chapter VIII.

Dynamic Barriers

The dynamic barriers require continued action to maintain their existence. These include the extraction trough type, the injection ridge type, and various combinations.

To maintain the effectiveness of a dynamic barrier of either the injection or extraction type, the greater specific gravity of saline water must be overcome. The specific gravity of sea water is 1.025 times that of fresh water. Thus, in an intruded aquifer which is 200 feet below sea level, a head of 205 feet of fresh water must be maintained by injection wells at the base of that aquifer to just balance the extra weight of the alien fluid. Similarly, for an extraction barrier, it would be necessary to maintain heads at least 5 feet below the inland pumping trough to balance the weight of saline waters at 200 feet below sea level. In Santa Ana Gap, saline waters have intruded aquifers to a depth of 200 feet. This is thought to be the greatest depth at which intrusion will occur before barriers are installed. Because of this condition, it is considered that a differential pressure head of 5 feet at either an injection or extraction barrier will protect the ground water basin. Actually, the intruding waters are diffused and their specific gravity is somewhere between that of fresh water and sea water, so a head of 5 feet above sea level would afford protection to a depth greater than 200 feet.

In the investigation reported here, after proposed barrier locations had been selected, transmissibility sections were prepared along each of the alignments for the purpose of determining the quantity of ground water flow. At each of these sections calculations were made to determine the amount of water (injected or extracted) required to form a barrier which would adequately protect the basin in the period of operation during which the lowest levels along Bolsa Avenue are expected to occur. Because any assumptions, estimates, and predictions of future water level elevations are subject to large error, two elevations along Bolsa Avenue were utilized for the purpose of determining barrier water requirements. As previously indicated, these elevations were 30 feet below mean sea level and 50 feet below mean sea level.

<u>Extraction Trough</u>. The construction of an extraction, or pumping trough, barrier was considered along Alignment No. 2 shown on Plate 15.

This type of barrier is composed of a linear system of pumping wells which depress the piezometric water surface to elevations slightly lower than those in the remainder of the basin. Conditions were determined for the extraction necessary to adequately protect the waters of Anaheim Basin during periods of ground water elevations of 30 and 50 feet below sea level at Bolsa Avenue. This system would consist of 20 to 25 extraction wells pumping continuously from the aquifers. The water extracted would be discharged to the Santa Ana River and the surface drainage channels in the gap.

The advantages of an extraction trough barrier in the Santa Ana Gap are noteworthy. With proper operation, little or no fresh water need be wasted because the seaward gradient (between lowest levels in the basin, and the extraction barrier trough in the gap) would be quite flat, while the landward gradient (between the ocean and the barrier trough) would be relatively steep. In addition, high water levels which might cause waterlogging conditions would not occur. Installation of the system along Alignment No. 2 would preserve a large portion of the ground water basin for potential future use.

The disadvantages of the pumping system tend to overshadow its advantages. During times of minimum ground water level elevation, it will be necessary to maintain the internodal pressure elevations (midway between pumping wells along the extraction trough) at 35 to 55 feet below sea level. In all probability, operations approaching this level would produce significant dewatering and subsidence in the peat soils. It appears that maintenance of saturated conditions in the peats is the only practical means of precluding subsidence. If piezometric levels in the Talbert aquifer were held at the above elevations, it would become necessary to apply water at or near the surface to maintain semiperched levels above sea level. In addition to potential subsidence problems, the extraction barrier would require a staff of skilled personnel for continued operations. This is an operational disadvantage when compared to the maintenance of a static barrier.

The concomitance of extraction with peat subsidence suggests that, unless relatively inexpensive means can be developed to control this subsidence, other methods should be employed to control saline invasion. To prevent significant subsidence as a result of dewatering peat deposits, ground water levels should probably not be continuously drawn down more than about 5 feet below sea level for any barrier project in the Santa Ana Gap area.

Injection Ridge. The construction of an injection ridge barrier was considered along Alignment No. 1 shown on Plate 15. This type of barrier comprises a linear system of injection wells which would form an elongated mound in the piezometric surface with internodal elevations of approximately 5 feet above sea level. Conditions were determined for the injection necessary to adequately protect the waters of Anaheim Basin during periods of minimum ground water level elevations. As previously stated, consideration was given to ground water levels of 30 and 50 feet below sea level in the vicinity of Bolsa Avenue. The injection system would contain 20 to 25 wells through which imported waters (or possibly reclaimed waste waters, i.e., tertiary treated sewage effluent) would be injected into the six aquifers subject to saline intrusion which underlie Alignment No. 1.

The advantages of an injection ridge barrier in Santa Ana Gap include the complete control of all saline water without additional facilities, the alleviation of subsidence hazards within the gap, and the use of reclaimed water. If an injection ridge were constructed along the proposed alignment, no supplemental extraction of degraded waters would be required because the alignment is landward of all such waters. Injection at Alignment No. 1 would thus preclude movement of saline waters into the basin. In addition, as ground water levels would remain relatively high (at or above sea level) within the major part of the gap, peat soils in the gap would remain in their present state of saturation and no significant subsidence would result.

The disadvantages of an injection system include the probability of waterlogging of surface sediments near the injection wells. Furthermore, extractions seaward of the barrier would have to be carefully controlled or prohibited, since they would increase barrier water requirements. Thus the shallower aquifers underlying a major portion of Santa Ana Gap would be at least partially abandoned. Waterlogging conditions would in all probability occur over the lowest portions of the alignment in the gap because, in order to maintain the desired pressure elevation at internodal points when the injection system commences operation, pressure levels at the injection wells would be at or near ground surface. Similar high pressure levels existed in historic times within Santa Ana Gap; prior to 1900, organic sediments were completely waterlogged and springs and swamps were abundant. At that time, the Santa Ana Gap and Bolsa Gap areas were known as "Gospel Swamp".

Because of reduction of permeability in the aquifers immediately adjacent to the wells as injection continues, injection water heads must be increased. The experience of the Los Angeles County Flood District indicates that injection head requirements may increase at the rate of 0.10 foot per day, or about 37 feet per year. These conditions would require pressure operations at every injection well within the gap. Under pressure conditions just prior to well redevelopment it is likely that upward leakage through peat soils and sand stringers would cause significant waterlogging of surface materials near the injection wells.

The disadvantages of the injection system appear so considerable, because of probable waterlogging within the gap, that it is a less than satisfactory method of controlling sea-water intrusion in this case. For this reason, it appears more desirable to devise some means of constructing an adequate salinity barrier which would result in the maintenance of internodal elevations at about sea level along the injection alignment.

Combined Injection Ridge and Extraction Trough. The construction of a combined injection-extraction barrier was considered during the study, assuming injection at Alignment No. 1 concurrent with extraction at the seaward Alignment No. 2. The locations of these alignments are shown on Plate 15. This type of barrier would include two systems of wells that, when operating conjunctively, would cause a continuous flow of water from the injection alignment seaward toward the system of pumping wells. Assumptions were based on operations at an internodal piezometric head of sea level along the injection alignment and a depressed head of 5 feet below sea level along the extraction alignment. Conditions were determined for the extraction and injection necessary for adequate protection of the waters in Anaheim Basin during periods of minimum water level elevation. The combined system would consist of 20 to 25 wells injecting water along Alignment No. 1, and 5 to 10 wells pumping continuously from the aquifers underlying Alignment No. 2 and discharging to the Santa Ana River and the surface drainage system in the valley.

The combined injection-extraction system in Santa Ana Gap includes some of the advantages but not the major disadvantages inherent in either system acting alone. If operational levels are chosen at about sea level for the injection ridge and 5 feet below sea level for the extraction trough, the adverse effects of waterlogging at the injection alignment and subsidence of dewatered peat soils at the extraction alignment would be minimized. These operating conditions would impose a continuous gradient from the injection line to the extraction line that would be sufficient to control invasion of saline water.

The disadvantages of this system include the construction of two separate systems, and the increased operational personnel and power requirements. In addition, as in the case of an injection ridge barrier, a major portion of the Santa Ana Gap area would be at least partially abandoned as a ground water unit because of the northerly location of the injection alignment. It would be necessary to carefully control ground water extractions from the shallow aquifers south, or seaward, of the injection barrier. It should be noted, however, that extraction would still be possible from those aquifers in the Santa Ana Gap area not subject to the invasion or influence of saline ocean waters.

CHAPTER VIII. COSTS OF SALINITY BARRIERS

In the preceding chapter, four types of barriers for controlling sea-water intrusion were discussed from the standpoint of the physical problems involved. These four types and their alignments are shown on Plate 15, and may be described as follows:

1. A static barrier - Alignment No. 2.
2. An extraction (pumping trough) barrier - Alignment No. 2.
3. An injection (pressure ridge) barrier - Alignment No. 1.
4. A combination barrier consisting of an injection ridge - Alignment No. 1, and an extraction trough - Alignment No. 2.

After locating a number of the most feasible barrier alignments dictated by existing physical conditions, the selection of one particular remedial measure or a combination of measures, which accomplish the same objective (in this case, protection of Anaheim Basin from saline intrusion through Santa Ana Gap), is based upon the cost over the economic life of the facility. Undesirable aspects or effects caused by the chosen activity must also be considered. Unfortunately, some side consequences of action such as waterlogging or surface subsidence are very difficult to evaluate in terms of cost.

In this chapter, barriers will be evaluated and compared on the basis of first cost, present worth, and annual cost. The economic life of the project is taken as 50 years of continuous service. For capital recovery determinations, interest is assumed as 4 percent per annum.

In comparing the costs of these barriers it has been anticipated that each will have to protect the basin during periods of minimum ground water level elevations. Costs have been compared for protection of the basin under two conditions, when ground water elevations in the vicinity of Bolsa Avenue are 30 feet, and 50 feet below sea level.

Permanent features, such as pipeline, vaults, maintenance station, wells, well casing, and the fixed physical barrier, are assumed to be designed for a life expectancy of 50 years. Appurtenant equipment which requires periodic replacement in whole or part has been assigned a reasonable life expectancy, and costs have been calculated for 50 years of service. These costs could be reduced somewhat by using smaller pumps, pump components, and motors in the early stages and replacing them at each replacement period with larger components to handle the anticipated increased flows. Although these refinements have not been included, it should be recognized that stage construction of the dynamic barriers is possible and these factors will be an important part of any final analysis and design.

It is assumed that the barrier facilities will be constructed entirely within existing street right-of-way along the suggested alignments, and that no right-of-way costs will be charged to the barrier. Because of the location of proposed works in parking or paved areas, all pumps, valves, and injection wellhead installations must be enclosed in reinforced concrete vaults below the ground surface.

The soils in the gap are expected to be aggressive with respect to ferrous metals, and a portion of the barrier project involves transporting saline waters, which are also aggressive to ferrous metals. For these reasons, steel pipe may not serve for the 50-year life design criterion; the use of asbestos-cement pipe (ACP) is assumed for all supply and discharge lines and for all well casing. Power costs have been determined from detailed estimates based on Southern California Edison Company schedule PA-1, revised July 1, 1964.

Static Barrier

A permanent static or physical barrier consisting of an impermeable wall or membrane should, if properly installed, prevent saline intrusion. Alignment No. 2 would be the most economical location for this type of barrier because of least length and depth. This wall may be considered permanent for the 50-year period of analysis.

As discussed previously, piezometric levels in the basin are expected to decline below sea level as a result of ground water basin operation. This will probably cause dewatering of the peat soils which occur in several areas in the gap, as shown on Plate 4B. Dewatering in turn will probably cause subsidence inland of the barrier. Some subsidence has already occurred in the area as a result of both drainage of the soils for agricultural purposes, and decline in piezometric levels in the Talbert aquifer. No costs for protection against such subsidence have been included in the estimates for the static or extraction barriers. Methods of spreading or injecting water at or near the surface into these peats could probably be devised, but such plans are beyond the scope of this report. It is estimated, however, that the cost of such methods would at least equal the costs of an injection ridge similar to the one described in this report. The lands and improvements affected could be acquired, but the cost of this protective action would exceed 100 million dollars.

Bulletin No. 63 contains a fairly complete analysis and cost comparison of several types of permanent barriers using slurries of bentonitic clay and drilling muds with various admixtures. An estimate prepared

PROPOSED EXTRACTION
BARRIER ALIGNMENT

A view looking west across Santa Ana Gap from Newport Mesa, showing the terrain along the proposed extraction alignment.

in 1954 by the Macco Corporation of the cost of constructing a slurry-filled trench barrier using specially built trenching machinery and selected backfill was included in that report. The estimated unit price was $2.04 per square foot of barrier. Applying "Engineering News Record" indexes for water works construction for 1954 and 1963 indicates that the present cost of building this type of barrier would approximate $12,000,000.

In this investigation, it was determined through consultation with representatives of Macco Corporation and Cronese-Terminal Drilling Company that an alternative method of overlapping drill holes filled with slurry and selected backfill offered better prospect of fulfillment than the trench-slurry method. From cost data provided by the two companies named, an estimation of costs, as shown in Table 7, for a barrier 200 feet deep, 21,000 feet long, and 2.25 feet thick was made on Alignment No. 2 for the drilled hole method.

TABLE 7

COSTS OF A STATIC BARRIER

Item	First cost	Present worth	Annual cost
Construction	$9,000,000	$9,000,000	$419,000
Operation and maintenance	--	215,000	10,000
TOTALS	$9,000,000	$9,215,000	$429,000

Extraction Barrier

In order to protect the basin during a period of minimum ground water level elevations, it would be necessary to maintain the internodal elevations of the extraction barrier approximately 5 feet below the lowest level of piezometric elevations in the basin. Drawdown in the wells is assumed as 15 feet below the required internodal elevations after equilibrium is established. The pumping rate is assumed as 500 gallons per minute per well. With pressure elevations at Bolsa Avenue assumed to be 50 feet below sea level, the total extraction requirement is 18,000 acre-feet per year. At the above pumping rate, 23 discharge wells along Alignment No. 2 would be required with an average depth of 163 feet.

Table 8 gives estimated costs of the barrier. Well construction, including 12-inch diameter ACP casing and electric logging, is estimated to cost $9,380 per well. Vaults to hold the pumps and valves at the wellheads are estimated to cost $3,200 each. These wells are assumed to require reconditioning once every 6 years at a cost of $1000 per well.

TABLE 8

COSTS OF AN EXTRACTION BARRIER

Item	Water level elevations at Bolsa Avenue					
	30 feet below mean sea level			50 feet below mean sea level		
	First cost	Present worth	Annual cost	First cost	Present worth	Annual cost
23 wells and appurtenances (valves, meters, controls, etc.)	$317,000	$ 317,000	$ 14,800	$317,000	$ 317,000	$ 14,800
69 observation wells	128,000	128,000	5,800	128,000	128,000	5,800
Discharge lines	123,000	123,000	5,700	123,000	123,000	5,700
Pumps and motors	23,000	107,000	5,000	28,000	131,000	6,200
Supply depot and laboratory	50,000	50,000	2,400	50,000	50,000	2,400
Power	--	265,000	12,300	--	562,000	26,000
Water (650 AF/year at $20 per acre-foot)*	--	200,000	13,000	--	280,000	13,000
Well reconditioning	--	75,000	3,500	--	75,000	3,500
Operation and maintenance	--	1,100,000	51,000	--	1,100,000	51,000
Subtotal	$641,000	$2,365,000	$113,500	$646,000	$2,766,000	$128,400
Contingencies (15 percent of first cost)	96,000	96,000	4,500	97,000	97,000	4,600
TOTALS	$737,000	$2,461,000	$118,000	$743,000	$2,863,000	$133,000

*Wasted due to seaward flow.

About 69 small (2-inch diameter) observation wells with plastic casing would be required to monitor the effectiveness of the pumping trough.

Grades along the chosen alignment are so flat that extremely large pipes would be required to carry the anticipated flows in a gravity system. Therefore, gravity waste lines are not considered economically feasible, and the estimate in Table 8 was drawn on the premise that pressure lines would be used. It is assumed that saline waters produced will be discharged into the Santa Ana River or the Central Valley Channel.

Injection Barrier

In Chapter IV reclaimed waste water from the County Sanitation Districts of Orange County is suggested as a continuously available source of water suitable for injection in a barrier. Treatment Plant No. 1, shown on Plate 15, processed 31,000 acre-feet of waste water in the 1963-64 fiscal year. The total injection requirement to protect the basin when water elevations are 50 feet below mean sea level at Bolsa Avenue is 17,000 acre-feet per year. Based upon estimates obtained from the Orange County Water District, the cost of treating and chlorinating waste water for injection is considered to be $20 per acre-foot. This price is generally comparable with unsoftened Colorado River water from the Metropolitan Water District and less costly than water from the State Water Project, both delivered at the same point.

With internodal pressure elevations at the barrier of 5 feet above mean sea level and water level elevations in the basin averaging 30 feet below mean sea level at Bolsa Avenue, the total amount of water required for the injection barrier would be 11,300 acre-feet per year (7,000 gallons per minute) of which 1,150 acre-feet per year would be wasted due to seaward flow. The same amount of waste to the ocean would occur with water level elevations at Bolsa Avenue averaging 50 feet below mean sea level.

From examination of the problems encountered by the Los Angeles County Flood Control District in its work on a barrier in the Manhattan Beach area, injection rates of 300 to 500 gallons per minute per well are considered reasonable for an injection system in the vicinity of Alignment No. 1. With a maximum injection rate of 500 gallons per minute and water level elevations at Bolsa Avenue of 50 feet below sea level, 23 wells would be required. They should be spaced approximately 850 feet apart. Along the basic barrier alignment, the wells would have an average depth of 350 feet. It is estimated that the wells would cost $16,400 each. This price includes the drilling of 24-inch holes, gravel pack, 12-inch ACP casing, plastic tremie pipes, electric logging, grouting, and well development. It is estimated that approximately 15 feet of head will be required to inject the design flow into the aquifer, and that this will increase approximately 0.1 foot per day. It is anticipated that reconditioning of the injection wells will be required at least once each year at a cost of $2,500 per well. Total lift for the supply pumps is estimated at 80 feet. About 69 observation wells of 2-inch diameter will be required at a cost of approximately $6,200 each. The project also includes 20,500 feet of 30-inch ACP and 3,000 feet of 12-inch ACP supply line, as well as pumps, pump houses, and appurtenant equipment. Costs of an injection barrier are shown in Table 9. No attempt was made to estimate the costs of preventing or ameliorating waterlogging of peat deposits.

EASTERN PORTION
OF PROPOSED
INJECTION ALIGNMENT

View looking west across Santa Ana Gap from Newport Mesa along the proposed injection alignment to Cannery Street. The Orange County Sanitation District's Treatment Plant No. 1 is in the center of the picture, adjacent to the Santa Ana River.

TABLE 9

COSTS OF AN INJECTION BARRIER

Item	Water level elevations at Bolsa Avenue					
	30 feet below mean sea level			50 feet below mean sea level		
	First cost	Present worth	Annual cost	First cost	Present worth	Annual cost
23 injection wells (12-inch, gravel packed) (valves, meters, controls, etc.)	$ 432,000	$ 432,000	$ 20,100	$ 432,000	$ 432,000	$ 20,100
69 observation wells (2-inch plastic)	345,000	345,000	15,900	345,000	345,000	15,900
Supply line	617,000	617,000	28,700	617,000	617,000	28,700
Pumping station and laboratory	95,000	95,000	4,400	95,000	95,000	4,400
Pumps and motors	12,000	34,000	1,600	15,000	42,000	2,100
Power for pumps	--	237,000	10,800	--	452,000	21,300
Water (1,150 AF/year at $20 per acre-foot)*	--	495,000*	23,000*	--	495,000*	23,000*
Operation and maintenance	--	1,100,000	51,000	--	1,100,000	51,000
Well reconditioning	--	1,235,000	57,500	--	1,235,000	57,500
Subtotal	$1,501,000	$4,590,000	$213,000	$1,504,000	$4,813,000	$224,000
Contingency (15 percent of first cost)	225,000	225,000	1,000	225,000	225,000	1,000
TOTAL	$1,726,000	$4,815,000	$214,000	$1,729,000	$5,038,000	$225,000

*Volume and costs are for injection water moving seaward only. Present worth and annual costs of total barrier water requirement would be $4,613,000 and $215,000 respectively, for water level elevations at Bolsa Avenue of 30 feet below sea level and $7,202,000 and $335,000 for water level elevations of 50 feet below sea level at Bolsa Avenue. The major portion of this flow is in a landward direction and provides recharge for the basin. Thus only the seaward flow is a proper charge against the barrier.

Combined Injection and Extraction System

On the basis of maintaining elevations at sea level for the injection portion and 5 feet below sea level for the extraction portion with levels at Bolsa Avenue of 30 feet below sea level, the amount of injection water required is 11,100 acre-feet per year. This flow would require 23 wells, operating at an injection rate of 300 gallons per minute per well. These quantities are essentially the same as those included in the injection system acting alone. The extraction barrier for the combined system at the level indicated would require pumping of 4,000 acre-feet per year. At a pumping rate of 300 gpm per well, eight wells would be required.

The cost estimates for this combined system reflect the cost of these eight wells and the appurtenant discharge line added to the complete injection system as estimated above. It is to be noted that as long as the barrier elevations are held constant, the requirements of the extraction portion of this barrier and the water wasted due to seaward flow from the injection portion remain constant regardless of water levels in the basin. Costs of a combined system are shown in Table 10.

TABLE 10

COSTS OF A COMBINATION INJECTION-EXTRACTION BARRIER

Item	Water level elevations at Bolsa Avenue					
	30 feet below mean sea level			50 feet below mean sea level		
	First cost	Present worth	Annual cost	First cost	Present worth	Annual cost
23 Injection wells	$ 432,000	$ 432,000	$ 20,100	$ 432,000	$ 432,000	$ 20,100
8 Extraction wells	110,000	110,000	5,100	110,000	110,000	5,100
93 Observation wells	390,000	390,000	18,500	390,000	390,000	18,500
Supply line (injection system)	617,000	617,000	28,700	617,000	617,000	28,700
Discharge line (extraction system)	106,000	106,000	5,000	106,000	106,000	5,000
Pumping Station and laboratory	95,000	95,000	4,400	95,000	95,000	4,400
Pumps and motors	20,000	71,000	3,300	23,000	79,000	4,000
Power	--	293,000	13,400	--	508,000	24,300
Well reconditioning	--	1,260,000	58,700	--	1,260,000	58,700
Operation and maintenance	--	1,100,000	51,000	--	1,100,000	51,000
Water (2,410 AF/year at $20 per acre-foot)*	--	1,035,000*	48,200*	--	1,035,000*	48,200*
Subtotals	$1,770,000	$5,509,000	$256,400	$1,773,000	$5,732,000	$268,000
15-percent contingencies	265,000	265,000	12,600	266,000	266,000	13,000
TOTALS	$2,035,000	$5,774,000	$269,000	$2,039,000	$5,998,000	$281,000

*See note on Table 9.

Comparison of Costs

The discussion of comparison of costs in this section is separated into comments pertaining to specific costs and other costs.

Specific Costs

The specific costs of construction and operation of the four barrier types considered in this report are summarized for comparison in Table 11. The ground water levels at Bolsa Avenue are assumed for this summary to be 50 feet below sea level.

TABLE 11

COMPARISON OF BARRIER COSTS

Barrier type	Water level elevation at Bolsa Avenue: 50 feet below mean sea level		
	First cost	Present worth	Annual cost
Static	$9,000,000	$9,215,000	$429,000
Extraction	743,000	2,863,000	133,000
Injection	1,729,000	5,038,000	225,000
Combination injection-extraction	2,039,000	5,998,000	281,000

A comparison of the present worth and annual costs of capital recovery and operation indicates that the static barrier is the most expensive of the plans studied and that the extraction barrier is the least expensive of the plans studied. The costs indicated in Table 11 represent construction and operation costs and the costs required to purchase property for the installation of a static barrier (the other types of barriers will not incur right-of-way costs since facilities will be located on public land). Concomitant effects, which would result from the operation of these barriers, are not included under the specific costs, but are included in the following paragraphs as other costs.

Other Costs

During the geologic phases of the study approximately 1,100 acres within the Santa Ana Gap were determined to be subject to subsidence and/or waterlogging because of the presence of peat deposits. The peat and organic soils subject to such subsidence or waterlogging (as the case may be) appear to be largely confined to the area seaward of Bolsa Avenue within Anaheim Basin. Therefore the effects of subsidence which will follow a lowering of the water table would be substantially confined to Santa Ana Gap and the area to the immediate north. However, extensive areas of Santa Ana Gap are presently being developed into single and multistory residential subdivisions, as shown in the illustrations of Santa Ana Gap in 1964 accompanying this report. These developed residential areas can be conservatively estimated to have a land and property value of $150,000 per acre.* Much of the land presently used for agricultural purposes has a selling price of $30,000 or more per acre (reflecting its potential value as residential land rather than its value for agricultural purposes).

The property values within the Santa Ana Gap which are subject to loss by subsidence or waterlogging represent a present market value of perhaps 100 million dollars. The severe problems which can result from the general lowering of the water table and/or the operation of a salinity barrier are critical, and the secondary costs** to remedy or alleviate the problems far outweigh the specific costs of the barrier indicated in Table 11.

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*At $25,000 for house and lot and with six units per acre.

**Actually these "costs" are more in the nature of negative benefits involved in preventing saline intrusion, but since they can be minimized by one type of barrier they can be discussed as costs involved in barrier choice.

Static Barrier. The operation of a static barrier would create problems of subsidence in areas landward of the barrier. During the geologic phases of the study approximately 1,100 acres within Santa Ana Gap were determined to be subject to such subsidence because of the presence of peat. It was noted that some areas have already experienced substantial subsidence, in some cases up to 20 feet, because the level of saturation has been lowered in the peaty materials. A further lowering of ground water levels inland of a static barrier would certainly seriously aggravate the problem. Actually it would not be the barrier per se that would cause the additional subsidence. However, the continued lowering of water levels, resulting from the amount of extraction expected and the absence of saline intrusion would certainly make necessary either the outright purchase of property damaged or litigation for damages, which would total many times the cost of constructing the barrier.*

Extraction Barrier. The extraction barrier entails the same problem of protection against subsidence as does the static barrier. When these costs are considered, this type of barrier becomes much more costly than either of the systems described below.

Injection Barrier. An injection system acting alone would tend to return water levels in the vicinity of the barrier to historic highs and recreate the ponds and springs which existed in the peat deposits.

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*Without a barrier and with extensive inland extractions, water levels in the gap might not be maintained by intrusion of ocean water and some subsidence would tend to occur. Because peat soils do not act as a sponge, but remain relatively consolidated once they have been dewatered and subsidence has taken place, a series of depressions would remain. Some of these might be low enough to later be filled with rising ground water.

These deposits underlie about 1,100 acres. It might also create new ponds and springs where subsidence had occurred when the ground water table was lowered. Waterlogging would be minimal in peat deposits located landward of the injection ridge, because hydraulic gradients on that side of the barrier would experience a rapid drop-off to lowered ground water levels within the basin. The largest portion (770 acres) of the peaty and organic soils occur seaward of the proposed injection barrier. While not all this acreage will be subject to waterlogging and not all the existing acreage has been improved, the damage which can be expected to occur to structures and the decrease in affected land values will certainly amount to millions of dollars. Thus, significant amounts of money, probably amounting to much more than the direct costs of constructing the injection barrier, would be required to purchase property and pay damages.

Combination Injection and Extraction Barrier. A salinity barrier system composed of both an injection and an extraction system operating in conjunction would minimize the effects of subsidence and waterlogging which have been described in this report. The pressure ridge, forming the landward side of the barrier system and operating so as to maintain internodal ground water elevations at sea level, would maintain the peat deposits in its vicinity in a saturated condition. At the same time the extraction trough, forming the oceanward side of the barrier system, with internodal ground water elevations maintained at 5 feet below sea level, would prevent excessive waterlogging of the peat deposits oceanward of the pressure ridge. Waterlogging would be minimal in any peat deposits landward of the pressure ridge, because hydraulic gradients on that side of the barrier would experience a rapid drop-off to the lowered ground water levels. The sequence of installation of the extraction and injection components would be dependent upon hydrologic conditions prevailing in Santa Ana Gap at the time of construction.

Should it ever become necessary or desirable to reduce the levels near Bolsa Avenue more than 50 feet below sea level, this combined system is flexible enough to permit modification by the addition of injection wells and larger pumps to provide for the increased injection water requirement for any operating level within the basin. The quantity of subsurface flow moving seaward from the injection portion of the barrier, and the quantity of water pumped from the extraction portion of the system, would remain relatively constant regardless of operating levels within Anaheim Basin.

CHAPTER IX. SUMMARY OF FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Findings

During the course of this investigation the findings listed below were determined:

1. Because past ground water extractions have exceeded natural replenishment, piezometric levels have periodically been below sea level since the mid-1920's in the Santa Ana Gap. This condition has allowed saline waters to move inland under the resulting landward hydraulic gradients.

2. By 1963, saline waters in the Santa Ana Gap area had progressed a maximum of nearly 4 miles inland from the ocean, and waters exceeding 500 parts per million chloride ion concentration underlay an area of approximately 5,100 acres.

3. The geologic framework of the area allows saline waters to move unimpeded from the ocean inland across the Newport-Inglewood fault system within the Talbert aquifer, which is the principal aquifer of the area. North of Indianapolis Avenue, saline waters can move laterally and downward into upper and lower Pleistocene aquifers.

Conclusions

As a result of the investigation described in this report, it is concluded that:

1. Considerations of historical piezometric levels, ground water supply, and water utilization, and probable future supply and utilization conditions, indicate that piezometric levels near Bolsa Avenue will probably decline to elevations of at least 30 feet below mean sea level.

2. In order to protect Anaheim Basin from further saline intrusion through Santa Ana Gap, it is necessary to construct and operate some type of salinity barrier in the gap area.

3. Four types of barriers can provide effective protection against saline intrusion in Santa Ana Gap. These are a static, or physical barrier; a pumping, or extraction trough; an injection ridge; and a combination of pumping trough and injection ridge operating conjunctively.

4. Operation of three of the types of barriers considered (static, extraction, and injection) would produce undesirable consequences of either subsidence or waterlogging, requiring resolution. Operation of a static barrier or an extraction trough would require the minimization of surface subsidence by maintaining the moisture content in the organic soils as a part of those barrier systems, or by acquisition of the affected land as a part of the barrier system. Operation of an injection barrier would require the minimization of the waterlogging of surface sediments. The problem of waterlogging could be solved either through drainage or through controlling land use by acquisition of the affected land as a part of an injection barrier system. The correction of these consequences is considered to be extremely costly and difficult, involving expenditure of many millions of dollars.

5. The cost of construction and operation (specific cost) of a combination injection-extraction barrier in Santa Ana Gap is higher than the cost of either plan separately. However, proper selection of operating characteristics for a combination barrier can result in a minimization of waterlogging and peat subsidence. If the large costs of protection against the effects of waterlogging or subsidence, inherent in the injection or

extraction barriers acting singly, were added to the project costs, either plan would far exceed the cost of the combined system. Therefore, the combination barrier is the most practical, desirable, and economical type of salinity control method for Santa Ana Gap.

6. Although insufficient data are available for Anaheim Basin as a whole to develop explicit figures on the economic benefits of preventing the intrusion of saline waters, it is obvious that the benefits are far greater than the specific costs of a barrier, and the costs connected with any negative benefits which may result from planned operation of the ground water basin. These negative benefits, specifically, possible subsidence and/or waterlogging of certain areas of organic soils, were treated as concomitant costs of barrier operation.

7. The most economical source of continuously available water for the injection phase of a combination barrier appears to be treated waste water from the County Sanitation Districts of Orange County.

Recommendations

To protect the waters of Anaheim Basin from impairment through saline water intrusion in Santa Ana Gap, it is recommended that the following measures be taken:

1. Further detailed study should be conducted at the local level to confirm project feasibility of the combination barrier prior to construction.

2. Treated effluent from the County Sanitation Districts of Orange County should be considered as a water supply for the injection portion of the barrier system. Injection of treated wastes should only

be done under rigidly controlled conditions and with the approval of the health departments having jurisdiction.

APPENDIX A

BIBLIOGRAPHY

APPENDIX A

BIBLIOGRAPHY

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APPENDIX B

DEFINITIONS

APPENDIX B

DEFINITIONS

The following words and terms are defined as used in this report:

Acre-foot. The volume of water required to cover one acre one foot in depth (43,560 cubic feet or 325,851 gallons).

Alluvium. A general term for stream deposited, sedimentary materials, usually of Recent geologic age.

Annual Cost. In general, the phrase is simply a short way of saying "equivalent uniform annual cost". To compare nonuniform series of money disbursements where money has a time value, it is necessary to make them comparable. This can be done by reducing each to an equivalent uniform annual cost or series of payments.

Anticline. Folded strata which dip in opposite directions from a common ridge or axis.

Artesian Well. Any artificial hole made in the ground through which water naturally flows from subterranean sources to the surface of the ground for any length of time.

Aquiclude. A geologic formation or zone, which, although porous and capable of transmitting water slowly, will not transmit it rapidly enough to furnish an appreciable supply for a well or spring.

Aquifer. A geologic formation, group of formations, or part of a formation that transmits water in sufficient quantity to supply pumping wells or springs.

Aquitard. A formation or part of a formation which retards water movement, but is permeable enough to permit appreciable slow movement.

Brackish Water. Water containing more than 1,500 but less than 10,000 parts per million of total dissolved solids.

Brine. Water containing more than 36,000 parts per million of total dissolved solids; as found in the Dead Sea and the Great Salt Lake for example.

Confined Ground Water. A body of ground water overlain by material sufficiently impervious to sever free hydraulic connection with overlying ground water except at the intake. Confined water moves in conduits under pressure due to the difference in head between the intake and discharge areas of the confined water body.

Connate Water. Water entrapped in the interstices of a sedimentary rock at the time it was deposited. These waters may be fresh, brackish, or saline in character. (Because of the dynamic geologic and hydrologic conditions in California, this definition has been altered in practice to apply to water in older formations, even though the water in these formations may have been altered in quality since the rock was originally deposited.)

Contamination. Defined in Section 13005 of the California Water Code: "...an impairment of the quality of the waters of the State by sewage or industrial waste to a degree which creates an actual hazard to public health through poisoning or through the spread of disease...." Jurisdiction over matters regarding contamination rests with the California Department of Public Health and local health officers.

Degradation. An impairment of the quality of water due to causes other than disposal of sewage and industrial waste.

Deterioration. An impairment of water quality.

Drawdown. The change in water surface elevation in a well as the result of pumping ground water.

Electrical Conductance. The reciprocal of the resistance in ohms measured between opposite faces of a centimeter cube of an aqueous solution at a temperature of 25 degrees centigrade.

Electric Log. The log of a well or bore hole obtained by lowering electrodes in the hole and measuring various electrical properties of the geologic formations traversed.

Equivalents Per Million (epm). Equivalent weights of solute contained in one million parts by weight of solution. For practical purposes, epm is the same as milliequivalents per liter (me/l).

Fault. A fracture or fracture zone along which there has been displacement of the two sides relative to one another parallel to the fracture. The displacement may be a few inches or many miles.

Fault System. More than one group of two or more related faults within an area.

First Cost. Initial expenditure (capital investment as opposed to operation and maintenance costs, or future expenditures).

Forebay Area. An area consisting of unconfined ground water where hydraulic continuity with the ground surface generally exists and which is located so as to provide a supply of ground water by subsurface flow to a body of confined ground water.

Fresh Water. Water containing less than 1,500 parts per million total dissolved solids.

Ground Water. Subsurface water occurring in the zone of saturation and moving under control of the water table slope or piezometric gradient.

Ground Water Basin. An area underlain by one or more permeable formations capable of furnishing a substantial water supply.

Ground Water Storage. That stage of the hydrologic cycle during which water occurs as ground water in the zone of saturation, including that part of such stage when water is passing through the zone of aeration and entering or leaving storage.

Hydraulic Gradient. Under unconfined ground water conditions, it is the slope of the profile of the water table. Under confined ground water conditions, it is the line joining the elevations to which the water would rise in wells if they were perforated in the aquifer.

Hydrology. The applied science concerned with the waters of the earth, their occurrences, distribution, use, and circulation through the unending hydrologic cycle of precipitation; consequent runoff, infiltration, storage, use, and disposal; eventual evaporation; and reprecipitation. It is concerned with the physical and chemical reaction of water with the rest of the earth, and its relation to the life of the earth.

Hydrology, Ground Water. The branch of hydrology that treats subsurface water: its occurrence, movement, and storage; its replenishment and depletion; the properties of unconsolidated materials and rocks that control the occurrence, movement, and storage of subsurface water; and the method of investigation and utilization of subsurface water.

Impairment. A change in quality of water which makes it less suitable for beneficial use.

Industrial Waste. Defined in Section 13005 of the California Water Code: "...any and all liquid or solid waste substance, not sewage, from any producing, manufacturing or processing operation of whatever nature."

Lithologic Log. The log of a well or bore hole obtained by examination and classification of drill cuttings from the geological formations traversed.

Normal Fault. A fault at which the hanging wall has been depressed, relative to the footwall.

Overdraft. The average annual decrease in the amount of ground water in storage that occurs during a long time period, under a particular set of physical conditions affecting the supply, use, and disposal (including extractions) of water in the ground water basin.

pH. The logarithm, to the base 10, of the reciprocal of the hydrogen ion concentration, or more precisely, of the hydrogen ion activity, in moles per liter. Distilled water (at 25 degrees centigrade) has a pH of 7; values less than 7 indicate acidic solutions while values greater than 7 indicate basic (alkaline) solutions.

Parts Per Million (ppm). One weight of solute per million weights of solution at a temperature of 20 degrees centigrade. For practical purposes, ppm is the same as milligrams per liter (mg/l).

Perched Ground Water. Ground water separated from an underlying body of ground water by unsaturated rock. Perched water belongs to a different zone of saturation from that occupied by the underlying ground water; its water table is a perched water table.

Percolation. The movement, or flow, of water through the interstices, or the pores, of a soil or other porous media.

Permeability. The capacity of a rock to transmit a fluid. Degree of permeability depends upon the size and shape of the pores, the size and shape of their interconnections, and the extent of the interconnections.

Permeability, Field Coefficient of. The amount of water moving through a unit area of aquifer per unit time under unit hydraulic gradient at the natural temperature. It is usually expressed in gallons per day per square foot.

Permeability, Coefficient of. Same as above, except that a reference temperature of 60 degrees Fahrenheit is defined. Units of permeability include cubic feet per second per square foot, acre-feet per year per square foot, etc.

Piestic Water. Water that occurs under artesian conditions.

Piezometer. A small-diameter observation well for the purpose of measuring the elevation of a piezometric surface and from which water samples may be obtained for water quality determinations.

Piezometric Surface. The surface to which the water from a given aquifer will rise in wells under its full head.

Pollution. Defined in Section 13005 of the California Water Code: "... an impairment of the quality of the waters of the State by sewage or industrial waste to a degree which does not create an actual hazard to the public health but which does adversely and unreasonably affect such waters for domestic, industrial, agricultural, navigational, recreational or other beneficial use, or which does adversely and unreasonably affect the ocean waters and bays of the State devoted to public recreation." Regional water quality control boards are responsible for prevention and abatement of pollution.

Postnate Waters. Waters which have partially or completely replaced connate waters in the interstices of a sedimentary rock. These waters may be fresh, brackish, or saline in character.

Present Worth. The present value of future expectations. From the viewpoint of an investor, the present worth of a future payment is the present investment necessary to assure that future payment. Or from the viewpoint of a borrower, present worth is the present sum which may be secured in exchange for the promise to make the specified future payment. The present worth factor is the reciprocal of the compound amount factor used in computing compound interest.

Pressure Area. A ground surface area underlain by an aquifer containing confined ground water.

Saline Water. Water containing more than 10,000 but less than 36,000 parts per million total dissolved solids.

Saline Water Invasion. The incursion of natively fresh aquifer units by percolation of industrial wastes, injection of brines through wells, or migration of modified connate waters from peripheral areas into the aquifer units. Such sources of salinity are independent of the sea.

Saline Wedge. The wedge-shaped body of saline water which enters along the bottom of an aquifer subject to saline intrusion, by virtue of the greater specific gravity of saline water compared to fresh water.

Salt Balance. The relationship of salt input to salt output. For example: to maintain usable quality of ground water, it is necessary to maintain a favorable salt balance where the total mass of dissolved salts entering a ground water basin from all sources of recharge is less than the total mass of dissolved salts removed from the basin by natural outflow and exported extractions.

Sea Water. Ocean water.

Sea-Water Intrusion. The introduction of actual sea water into previously fresh aquifer units by natural routes either from the sea or from tidal channels under the influence of a basinward hydraulic gradient. Interchange, through wells perforated in more than one aquifer from sea-water intruded units of higher head to fresh units of lower head, is a type of sea-water intrusion.

Semi-Perched Ground Water. Water which has a different pressure head than an underlying body of ground water, but which is not separated from the underlying body by any unsaturated rock.

Sewage. Defined in Section 13005 of the California Water Code: "...any and all waste substance, liquid or solid, associated with human habitation, or which contains or may be contaminated with human or animal excreta or excrement, offal, or any feculent matter."

Specific Yield. The ratio of the volume of water a saturated soil will yield by gravity, to its own volume, commonly expressed in percent.

Storage Coefficient. The volume of water released from storage in each vertical column of aquifer having a base one foot square when the water level declines one foot. In an unconfined aquifer the storage coefficient approximates specific yield; in a confined aquifer it is related to the elasticity of the aquifer and usually is very small.

Stress-Relief Fault. A fault or zone of weakness along which stresses in the earth's crust are relieved.

Strike-Slip Fault (Transcurrent Fault). A fault in which the net slip is practically in the direction of the fault strike.

Syncline. Folded strata in rocks which dip inward from both sides toward a common place or axis.

Total Dissolved Solids (TDS). The dry residue from the dissolved matter in an aliquot of a water sample remaining after evaporation of the sample at a definite temperature.

Transmissibility, Coefficient of. The rate of flow of water, in gallons per day, at the prevailing water temperature, through each vertical strip, one foot wide, having a height equal to the thickness of the aquifer and under a unit hydraulic gradient.

Unconfined Ground Water. Ground water not immediately overlain by impervious materials, and moving under control of the water table slope.

Waste Water. Water that has been put to some use or uses and has been disposed of, commonly to a sewer or wasteway. It may be liquid industrial waste or sewage or both.

Waterflooding. The secondary-recovery operation in which water is injected into a petroleum reservoir in order to displace and move residual oil toward a recovery well.

Water-Logging. Swampy conditions caused by a high water table.

Water Table. The surface of ground water at atmospheric pressure in an unconfined aquifer. This is revealed by the levels at which water stands in wells penetrating the unconfined aquifer.

Well. A shaft or hole sunk into the earth to obtain oil, gas, water, etc. or for the purpose of injection of fluids into the earth.

APPENDIX C

WELL DATA

APPENDIX C

WELL DATA

This appendix contains descriptions of wells and exploratory holes drilled in the course of the investigation.

In order to determine the subsurface geologic conditions within the study area, 29 exploratory holes were drilled to varying depths. A log was made of the lithology of each of these holes during drilling and, in addition, measurements were taken of the electrical properties of the geologic formations traversed in each of the holes. The logs obtained from these processes are known as "lithologic logs" and "electric logs", respectively.

Seventeen of the exploratory holes were backfilled upon completion of logging. Piezometers were constructed in the remaining 12 holes so that continuing observations could be made of water level fluctuations and water quality changes.

In this appendix, wells (piezometers) are listed numerically by DWR exploratory test hole number, i.e., "SA Number". Where more than one piezometer was installed in a single well (in some cases, one well contains three piezometers) the deepest piezometer is designated "A" and shallower piezometers are designated "B" and "C", if necessary. For example, in test hole SA-10, piezometer SA-10A is the deepest, SA-10B is intermediate in depth, and SA-10C is the most shallow of the three.

In addition to SA numbers, state well numbers are also listed. State well numbers were assigned only to holes in which piezometers were installed.

In the state well numbering system, wells are assigned numbers according to their location in the rectangular system for the subdivision of public land. For example, in the well number 6S/11W-1F2, that portion of the number preceding the slash indicates the township (T6S), that portion of the number between the slash and the hyphen is the range (R11W), the number between the hyphen and the letter indicates the section (Section 1), and the letter indicates the 40-acre subdivision of the section, as shown below, where A is NE 1/4 of the NE 1/4 of the Section.

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

1

Within each 40-acre tract the wells are numbered serially as indicated by the final digit. Thus, well number 6S/11W-1F2 is the second well to be listed in the SE 1/4 of the NW 1/4 of Section 1, T6S, R11W.

In this report and appendixes, all wells are referenced to the San Bernardino Base and Meridian.

APPENDIX C

WELL DATA

State well number and other number	Location	Aquifer	Date completed	Ground surface elevation[a]	Size of casing, in inches	Total depth in feet	Intervals of perforated casing, in feet	Data available			
								Litho log	Electric log	Water levels	Analyses
SA- 3 6S/11W- 1F2	830 feet north of Yorktown Avenue and 485 feet west of Harding Lane	Alpha	11- 9-62	57	2	400	100-160	X	X	X	X
SA- 4 6S/11W- 1Q2	1950 feet west of Cannery Street and 500 feet north of Adams Avenue	Talbert	9- 6-62	10	2	170	58-165	X	X	X	X
SA- 5A 6S/10W- 6J1	280 feet south of Yorktown Avenue and 50 feet west of Brookhurst Street	Main	2- 1-63	10	2	270	273-312	X	X	X	X
SA- 5B 6S/10W- 6J2	280 feet south of Yorktown Avenue and 50 feet west of Brookhurst Street	Lambda	2- 1-63	12	2	146	112-132	X	X	X	X
SA- 6A 6S/10W- 5K2	2950 feet east of Brookhurst Street and 2250 feet north of Adams Avenue	Main	12-27-62	32	2	313	263-298	X	X	X	X
SA- 6B 6S/10W- 5K3	2950 feet east of Brookhurst Street and 2250 feet north of Adams Avenue	Talbert-Beta (?)	12-27-62	32	1	142	99-139	X	X	X	X
SA- 7A 6S/10W- 9M3	4700 feet west of Harbor Boulevard and 1450 feet north of Section Line; west of Fairview State Hospital	Lower Pleistocene Sediments (undifferentiated)	12-13-62	62	1	384	358-379	X	X	X	X
SA- 7B 6S/10W- 9M1	4700 feet west of Harbor Boulevard and 1450 feet north of Section Line; west of Fairview State Hospital	Lower Pleistocene Sediments (undifferentiated)	12-13-62	62	2	304	220-290	X	X	X	X
SA- 7C 6S/10W- 9M2	4700 feet west of Harbor Boulevard and 1450 feet north of Section Line; west of Fairview State Hospital	Upper Pleistocene Sediments (undifferentiated)	12-13-62	63	1	205	158-200	X	X	X	X
SA- 8 6S/10W- 8C2	2100 feet east of Prookhurst Street and 950 feet south of Adams Avenue	Lower Main	11- 8-62	29	2	600[b] 309[c]	260-295	X	X	X	X
SA- 9 6S/10W- 8P1	1700 feet east of Brookhurst Street and 650 feet north of Atlanta Avenue (projected)	Talbert	12- 7-62	12	1	420[b] 110[c]	75-105	X	X	X	X
SA-10A 6S/10W- 7E2	2000 feet south of Adams Avenue and 1295 feet east of Cannery Street	Main	1- 4-63	8	2	345	300-330	X	X	X	X
SA-10B 6S/10W- 7E3	2000 feet south of Adams Avenue and 1295 feet east of Cannery Street	Lower Rho	1- 4-63	8	1	262	225-255	X	X	X	X

WELL DATA
(continued)

State well number and other number	Location	Aquifer	Date completed	Ground surface elevation[a]	Size of casing, in inches	Total depth in feet	Intervals of perforated casing, in feet	Data available: Litho log	Elec- tric log	Water levels	Analy- ses
SA-10C 6S/10W- 7E4	2000 feet south of Adams Avenue and 1295 feet east of Cannery Street	Talbert	1- 4-63	8	1	129	90-120	X	X	X	X
SA-11 6S/11W-12B2	1420 feet west of Cannery Street and 1220 feet south of Adams Avenue	Talbert	9-21-62	8	2	154	64-149	X	X	X	X
SA-12A 5S/10W-30L4	119 feet west of Bushard Street and 31 feet south of North curb of Slater Avenue	Lambda	3- 7-63	28	1	336	305-325	X	X	X	X
SA-12B 5S/10W-30L5	119 feet west of Bushard Street and 31 feet south of North curb of Slater Avenue	Beta	3- 7-63	28	1	261	236-256	X	X	X	X
SA-12C 5S/10W-30L6	119 feet west of Bushard Street and 31 feet south of North curb of Slater Avenue	Talbert	3- 7-63	28	1	132	86-126	X	X	X	X
SA-13	870 feet east of Beach Boulevard and 33 feet south of Ellis Avenue	----	2-20-63	60	7[d]	403	----	X	X		
SA-14	550 feet west of Cannery Street and 19 feet south of Ellis Avenue	----	2-25-63	14	7[d]	402	----	X	X		
SA-15	980 feet south of Ellis Avenue and 50 feet east of Bushard Street	----	3- 1-63	18	7[d]	534	----	X	X		
SA-16	1300 feet north of Garfield Avenue and 1300 feet east of Brookhurst Street	----	2- 8-63	18	7[d]	536	----	X	X		
SA-17	1125 feet south of Ellis Avenue and 450 feet west of Verano Street	----	10-23-62	24	7[d]	255	----	X	X		
SA-18	5200 feet east of Brookhurst Street and 1925 feet north of Adams Avenue	----	9-27-62	55	7[d]	403	----	X	X		
SA-19	50 feet west of Brookhurst Street and 33 feet south of Garfield Avenue	----	10-18-62	15	7[d]	208	----	X	X		
SA-20	500 feet west of Bushard Street and 30 feet south of Garfield Avenue	----	2-16-63	15	7[d]	435	----	X	X		
SA-21	2600 feet north of Adams Avenue and 1050 feet west of Bushard Street	----	9- 1-62	10	7[d]	504	----	X	X		

WELL DATA
(continued)

State well number and other number	Location	Aquifer	Date completed	Ground surface elevation[a]	Size of casing, in inches	Total depth in feet	Intervals of perforated casing, in feet	Data available: Litho log	Elec-tric log	Water levels	Analy-ses
SA-22A 6S/11W- 1J4	2638 feet south of Garfield Avenue and 1300 feet west of Cannery Street	Main	1- 9-63	7	1	367	300-332	X	X	X	X
SA-22B 6S/11W- 1J5	2638 feet south of Garfield Avenue and 1300 feet west of Cannery Street	Lambda	1- 9-63	7	1	181	155-176	X	X	X	X
SA-22C 6S/11W- 1J6	2638 feet south of Garfield Avenue and 1300 feet west of Cannery Street	Talbert	1- 9-63	8	1	135	109-130	X	X	X	X
SA-23	1960 feet north of Adams Avenue and 50 feet east of Beach Boulevard	----	1-25-63	53	7[d]	450	----	X	X		
S'·24	1880 feet east of Beach Boulevard and 660 feet south of Adams Avenue	----	1-16-63	7	7[d]	400	----	X	X		
SA-25	1050 feet north of Atlanta Avenue and 40 feet east of Cannery Street	----	11- 5-62	4	7[d]		----	X	X		
SA-26	2150 feet south of Adams Avenue and 950 feet west of Brookhurst Street	----	10- 4-62	8	7[d]	356	----	X	X		
SA-27	1050 feet west of Brookhurst Street and 48 feet south of Adams Avenue	----	11-15-62	12	7[d]	502	----	X	X		
SA-28	3000 feet south of Adams Avenue and 1650 feet east of Brookhurst Street	----	11-29-62	30	7[d]	348	----	X	X		
SA-29	3850 feet east of Brookhurst Street and 1400 feet south of Adams Avenue	----	10-27-62	10	7[d]	400	----	X	X		
SA-30A 6S/10W- 9E2	4400 feet west of Harbor Boulevard and 1450 feet south of Adams Avenue; northwest of Fairview State Hospital	(Main?)	12-19-62	70	1	219	171-214	˅	X	X	X
SA-30B 6S/10W- 9E1	4400 feet west of Harbor Boulevard and 1450 feet south of Adams Avenue; northwest of Fairview State Hospital	(Beta?)	12-19-62	70	1	130	104-125	X	X	X	X
SA-31	1420 feet south of Atlanta Avenue and 400 feet west of Cannery Street	----	10-11-62	4	7[d]	500	----	X	X		

a. In feet (USGS datum).
b. Total drilled depth.
c. Cased depth.
d. Not cased. Hole back filled on completion.

APPENDIX D

MINERAL ANALYSES OF GROUND WATERS

ANAHEIM BASIN, SANTA ANA GAP

APPENDIX D

MINERAL ANALYSES OF GROUND WATERS
ANAHEIM BASIN, SANTA ANA GAP

State well number	Date sampled	Temperature when sampled °F	pH	ECx10⁶ at 25° C	Constituents in parts per million / equivalents per million: Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	Parts per million: F	B	SiO_2	Total dissolved solids	Total hardness (Ca CO_3)	Percent Na	Character
									MAIN AQUIFER											
5S/11W-26P3	4- 7-62	67	8.4	373	9/0.46	0/0	74/3.20	0.5/0.01	2.11/0.07	161/2.63	25/0.53	19/0.53	1.3/0.02	0.7	0.13	13	230	23	87	Na HCO_3
6S/10W- 5K2	10- 3-63	72	8.3	342	15/0.75	4/0.33	52/2.26	1.3/0.03	0/0	143/2.34	34/0.70	13/0.37	0.4/0.0	0.4	0.10	18	231	54	67	Na HCO_3
- 6B3	12-26-61	64	8.5	352	12/0.59	2/0.20	65/2.83	0.5/0.01	6/0.2	174/2.85	13/0.26	15/0.42	0/0	0.7	0.12	12	206	40	78	Na HCO_3
- 6J1	3-20-63	68	9.8	538	3/0.15	0/0	109/4.73	4.3/0.11	60/2.00	55/0.90	31/0.64	55/1.55	0.6/0.01	0.5	0.09	17	285	8	95	Na CO_3-Cl
- 6K2	7-23-59	--	8.0	343	8/0.40	0.5/0.04	73/3.18	1.2/0.03	0/0	190/3.12	5/0.11	16/0.45	0.8/0.01	0.8	0.15	20	210	22	87	Na HCO_3
- 6N2	8- 7-63	69	7.8	510	9.2/0.46	3.3/0.27	104/4.5	1.6/0.04	0/0	271/4.45	13/0.28	14/0.4	0/0	0.8	1.34	14	336	37	86	Na HCO_3
- 7E2	10- 8-63	69	8.6	530	14/0.68	0.6/0.05	127/5.50	2.7/0.07	10.8/0.36	305/4.99	12/0.15	21/0.57	0/[illegible]	0.8	0.36	11	384	36	87	Na HCO_3
- 8C2	10- 4-63	72	8.6	1160	10/0.50	1.4/0.12	256/11.14	3.2/0.08	14/0.48	361/5.92	1.0/0.02	178/5.02	1.5/0.02	0.9	0.98	23	684	31	94	Na HCO_3-Cl
- 9E2	10- 2-63	--	8.6	695	5.4/0.28	0/0	152/6.61	1.4/0.04	21/0.72	232/3.80	1.9/0.04	83/2.34	1.5/0.02	1.1	0.76	17	447	14	95	Na HCO_3-Cl
- 9M1	10- 3-63	80	8.5	1316	10/0.50	0.9/0.08	273/11.88	2.4/0.06	4.8/0.16	261/4.28	0/0	279/7.87	0/0	1.2	1.03	21	777	29	95	Na Cl-HCO_3
- 9M3	10- 3-63	80	8.7	1592	10/0.50	1.9/0.16	327/14.22	2.6/0.07	14/0.48	234/3.84	0/0	372/10.49	1.3/0.02	1.1	1.06	18	885	33	95	Na Cl
-17M2	4- 4-63	69	7.9	8300	218/10.90	250/20.60	1550/67.50	35/0.90	0/0	555/9.10	503/10.47	2925/82.50	0.4/0.01	0.2	1.54	22	6060	1575	68	Na Cl
6S/11W- 1J4	10- 2-63	69	9.0	436	7.4/0.37	0.6/0.05	97/4.22	1.9/0.05	24/0.80	214/3.50	1.0/0.02	14/0.39	1.4/0.02	0.6	0.30	23	252	21	90	Na HCO_3

MINERAL ANALYSES OF GROUND WATERS
ANAHEIM BASIN, SANTA ANA GAP
(continued)

State well number	Date sampled	Temperature when sampled °F	pH	ECx10^6 at 25° C	Constituents in parts per million / equivalents per million									Parts per million						Character
					Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	B	SiO_2	Total dissolved solids	Total hardness ($Ca CO_3$)	Per-cent Na	
RHO AQUIFER																				
5S/10W-33D1	3-20-63	--	8.2	380	43/2.16	6.6/0.54	37/1.60	2.2/0.06	0/0	183/3.00	37/0.77	16/0.45	0/0	0.4	0.09	15	250	135	37	Ca-Na HCO_3
5S/11W-26M7	10- 3-61	77	8.7	391	6.3/0.32	0.7/0.06	82/3.57	2.1/0.05	14.6/0.49	198/3.25	4.4/0.09	0.12/0.34	--/--	--	0.16	--	286	19	89	Na HCO_3
6S/10W- 7E3	10- 9-63	67	9.6	510	13/0.64	0.6/0.05	115/5.00	2.0/0.05	64.2/2.14	156/2.56	17/0.36	18/0.49	0/0	0.8	0.30	11	364	35	87	Na HCO_3-CO_3
- 9M2	10- 3-63	78	8.8	877	5.0/0.25	1.0/0.09	190/8.27	2.1/0.05	16/0.56	244/4.00	0.5/0.01	136/3.84	1.0/0.01	1.2	0.91	21	539	17	95	Na HCO_3-Cl
6S/11W- 2A2	9-15-53	--	8.5	440	6.9/0.34	2.6/0.21	96/4.17	0.9/0.023	0/0	216/3.540	8.6/0.179	31/0.874	0.5/0.008	0.6	0.24	17	270	28	88	Na HCO_3
LAMBDA AQUIFER																				
5S/10W-30L4	10- 1-63	65	9.4	255	12/0.60	9.2/0.76	33/1.44	3.6/0.09	19/0.64	73/1.20	34/0.71	14/0.39	1.0/0.01	0.5	0.04	23	138	68	50	Na HCO_3-SO_4
6S/10W- 6D2	8-16-63	69	7.5	3450	442/22.05	37/3.05	240/10.40	8.5/0.22	0/0	102/1.67	101/2.09	1137/32.05	0/0	0.1	0.26	11	2312	1255	29	Ca Cl
- 6J2	10- 7-63	68	8.2	335	20/0.98	1.0/0.08	55/2.40	2.5/0.06	0/0	151/2.48	29/0.60	18/0.50	0/0	0.4	0.09	12	226	53	68	Na HCO_3
6S/11W- 1J5	10- 1-63	--	8.8	421	28/1.40	4.6/0.38	55/2.39	3.0/0.08	9.6/0.32	96/1.58	48/1.01	45/1.27	1.0/0.01	0.4	0.06	21	231	89	56	Na HCO_3-Cl
BETA AQUIFER																				
5S/10W-30L5	10- 1-63	--	8.4	397	44/2.20	7.0/0.58	33/1.44	3.2/0.08	0/0	190/3.12	34/0.70	12/0.34	1.5/0.02	0.5	0.12	30	219	139	33	Ca HCO_3
6S/10W- 4N1	1-12-62	--	8.6	981	10/0.49	5/0.40	195/8.47	2.1/0.05	21/0.70	253/4.15	10/0.20	163/4.58	0/0	0.4	0.95	15	590	45	90	Na Cl-HCO_3
- 9E1	10- 2-63	72	9.5	1342	6.1/0.30	0/0	296/12.88	3.8/0.10	8.4/0.28	382/6.26	37/0.77	198/5.58	1.3/0.02	0.8	0.86	19	808	15	97	Na HCO_3-Cl

MINERAL ANALYSES OF GROUND WATERS
ANAHEIM BASIN, SANTA ANA GAP
(continued)

State well number	Date sampled	Temperature when sampled °F	pH	ECx10^6 at 25° C	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	B	SiO_2	Total dissolved solids	Total hardness (Ca CO_3)	Percent Na	Character
					Constituents in parts per million / equivalents per million									Parts per million						
									ALPHA AQUIFER											
5S/10W-28B3	11-28-61	--	7.8	580	71/3.55	11/0.87	39/1.70	1.0/0.03	0/0	282/4.61	26/0.54	40/1.13	0/0	0.4	0.03	18	358	221	28	Ca HCO_3
-29F2	12- 5-61	--	7.3	410	44/2.22	11/0.88	35/1.50	1.3/0.03	0/0	207/3.40	37/0.76	13/0.34	0/0	0.4	0.07	17	326	155	27	Ca-Na HCO_3
5S/11W-25E5	12- 1-61	--	7.5	494	62/3.12	12/0.95	34/1.47	2.8/0.07	0/0	205/3.37	70/1.47	22/0.62	0/0	0.6	0.07	16	288	204	26	Ca HCO_3
-26C4	1-25-62	--	7.9	475	58/2.90	10/0.77	27/1.17	2.7/0.07	0/0	208/3.45	49/1.02	19/0.52	2.2/0.04	0.4	0.11	18	292	184	24	Ca HCO_3
-26F4	9-25-57	77	7.6	1473	198/9.90	33/2.75	30/1.30	3/0.08	0/0	211/3.46	124/2.50	282/7.95	5.8/0.09	0.3	0.15	--	792	633	9	Ca Mg-Cl
-35F4	8- 5-63	77	8.6	357	11/0.55	2/0.16	62/2.70	2/0.04	10/0.33	159/2.61	14/0.29	13/0.37	--/--	--	0.11	--	216	36	78	Na HCO_3
-36C2	6-28-63	--	8.2	480	52/2.61	10/0.82	33/1.43	2.8/0.07	0/0	205/3.37	43/0.91	21/0.60	1.0/0.02	0.4	0.07	16	290	172	29	Ca HCO_3
-36P1	3- 4-63	77	7.7	1666	199/9.93	34/2.80	64/2.78	5/0.13	0/0	221/3.62	77/1.60	365/10.28	5/0.08	--	0.05	--	1021	637	18	Ca Cl
6S/11W- 1D2	5-23-57	--	7.1	4285	520/26.0	75/6.15	192/8.35	8.6/0.22	0/0	204/3.35	60/1.25	1240/34.93	0/0	0.30	0.34	19	2526	1608	20	Ca Cl
- 1F2	10- 4-63	--	7.6	3367	410/20.46	82/6.74	119/5.18	9.0/0.23	0/0	95/1.56	105/2.19	975/27.50	2.6/0.04	0.2	0.15	29	2895	1360	16	Ca Cl
- 1N2	7-29-60	--	8.4	500	10/0.49	2/0.23	100/4.35	3.9/0.10	3.9/0.13	276/4.53	5/0.11	16/0.45	0.9/0.01	0.5	0.37	14	332	36	84	Na HCO_3
- 2J2	3-26-52	--	7.3	3776	466/23.3	86/7.06	220/9.58	9.7/0.25	0/0	271/4.44	56/1.16	1230/34.7	4.4/0.072	0.20	0.86	--	2680	1518	24	Ca Cl
-11G1	3- 4-63	77	7.5	1564	154/7.68	39/3.21	74/3.22	4/0.11	0/0	195/3.20	41/0.85	355/10.00	6/0.09	--	0.04	--	877	545	23	Ca Cl

MINERAL ANALYSES OF GROUND WATERS
ANAHEIM BASIN, SANTA ANA GAP
(continued)

State well number	Date sampled	Temperature when sampled °F	pH	ECx10[6] at 25° C	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	B	SiO_2	Total dissolved solids	Total hardness (Ca CO_3)	Percent Na	Character
					Constituents in parts per million / equivalents per million									Parts per million						
									TALBERT AQUIFER											
5S/10W-30L6	10- 1-63	65	8.6	434	34/1.70	10/0.86	43/1.87	4.1/0.10	17/0.56	123/2.02	55/1.14	29/0.82	1.4/0.02	0.5	0.04	24	238	128	41	Na-Ca HCO_3
-30N4	12-13-61	--	7.6	522	64/3.22	11/0.92	36/1.55	2.5/0.06	0/0	233/3.82	51/1.06	24/0.69	0/0	0.4	0.07	17	260	207	27	Ca HCO_3
-30P5	12-13-61	--	7.4	632	68/3.38	17/1.41	41/1.80	2.4/0.06	0/0	253/4.15	79/1.65	33/0.92	0/0	0.4	0.10	18	372	240	27	Ca HCO_3
-31A2	1- 3-62	--	8.2	605	58/2.92	19/1.62	37/1.60	2.2/0.06	0/0	249/4.08	62/1.31	33/0.92	0/0	0.5	0.17	16	456	227	26	Ca-Mg-Na HCO_3
-31C7	6-27-63	--	7.8	630	70/3.50	16/1.32	40/1.75	2.4/0.06	0/0	265/4.35	62/1.31	28/0.80	0/0	0.4	0.10	15	370	241	26	Ca HCO_3
-31F3	1-30-62	--	7.6	878	108/5.38	23/1.93	45/1.95	3.2/0.08	0/0	333/5.47	76/1.58	86/2.42	0/0	0.03	0.06	22	594	366	21	Ca HCO_3
-31G2	1- 2-62	--	8.0	428	43/2.16	10/0.83	30/1.30	2.0/0.05	0/0	192/3.15	38/0.81	17/0.47	0/0	0.4	0.12	18	380	150	30	Ca HCO_3
-31L2	11- 5-63	--	7.6	2690	335/16.72	82/6.76	153/6.65	6.3/0.16	0/0	166/2.72	61/1.27	920/25.95	0/0	0.1	0.20	16	2178	1174	22	Ca Cl
-31R7	6-27-63	--	8.2	570	49/2.46	21/1.73	39/1.70	2.3/0.06	0/0	259/4.25	45/0.95	21/0.60	0/0	0.4	0.07	17	340	210	29	Ca HCO_3
-32C11	12- 7-61	--	7.5	628	79/3.94	13/1.14	40/1.75	2.9/0.07	0/0	263/4.32	68/1.42	36/1.01	0/0	0.5	0.10	17	348	254	25	Ca HCO_3
-32D2	1-29-62	--	8.0	590	69/3.43	14/1.18	40/1.74	4/0.09	0/0	257/4.22	50/1.04	32/0.90	0/0	0.49	0.25	20	440	231	27	Ca HCO_3
-32N3	1- 3-62	--	7.8	589	71/3.57	12/1.00	35/1.50	2.1/0.05	0/0	247/4.05	60/1.25	26/0.72	0/0	0.4	0.14	16	394	229	25	Ca HCO_3
-32P3	9-11-63	77	7.6	753	82/4.09	20/1.64	46/2.00	3/0.08	0/0	271/4.44	106/2.21	45/1.27	3.8/0.06	0.31	0.03	16	455	287	26	Ca HCO_3
-33C2	3-20-63	69	7.8	720	51/2.56	14/1.18	100/4.35	1.8/0.05	0/0	195/3.20	177/3.69	46/1.27	0/0	0.2	0.12	15	480	187	53	Na SO_4-HCO_3

MINERAL ANALYSES OF GROUND WATERS
ANAHEIM BASIN, SANTA ANA GAP
(continued)

State well number	Date sampled	Temperature when sampled °F	pH	ECx10^6 at 25° C	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	B	SiO_2	Total dissolved solids	Total hardness ($CaCO_3$)	Percent Na	Character
					Constituents in parts per million / equivalents per million									Parts per million						
									TALBERT AQUIFER (continued)											
5S/11W-26F1	1-24-62	--	8.1	342	13/0.64	4/0.31	60/2.60	1.0/0.03	0/0	174/2.85	14/0.28	15/0.42	0/0	0.7	0.17	12	182	48	73	Na HCO_3
-36J2	1-30-62	67	8.0	680	81/4.06	15/1.23	37/1.60	3.5/0.09	0/0	233/3.81	55/1.14	74/2.10	1.8/0.03	0.2	0.13	19	430	265	23	Ca HCO_3
6S/10W- 5K3	10- 3-63	68	8.3	930	101/5.04	20/1.64	79/3.44	4.9/0.13	14/0.48	249/4.08	144/3.00	95/2.68	1.0/0.01	0.3	0.10	27	620	334	34	Ca-Na HCO_3-SO_4
- 6H2	12-26-61	--	7.9	768	85/4.24	16/1.34	42/1.83	2.2/0.06	0/0	223/3.65	25/0.52	120/3.38	0/0	0.3	0.12	16	484	279	25	Ca HCO_3-Cl
- 6L3	10-23-62	68	7.1	6000	609/30.40	120/9.90	575/25.00	11/0.29	0/0	311/5.10	17/0.37	2096/59.1	0/0	0.2	0.34	16	5060	2015	38	Ca-Na Cl
- 7E4	10- 9-63	65	7.8	7200	447/22.30	88/7.20	1080/46.95	13/0.34	0/0	272/4.47	10/0.21	2500/70.50	0/0	0.1	1.18	12	5382	1475	61	Na Cl
- 7J4	10-22-62	68	7.4	4400	427/21.30	75/7.20	437/19.00	11/0.29	0/0	143/2.35	8/0.17	1576/44.45	0/0	0.2	0.23	12	2796	1425	40	Ca-Na Cl
- 7M3	5-17-62	67	7.3	13340	612/30.54	174/14.30	2200/95.70	50/1.28	0/0	578/9.48	0/0	4700/132.54	1.0/0.02	0.76	2.73	18	8830	2237	67	Na Cl
- 7Q3	10-25-62	67	7.8	8900	952/47.50	158/13.00	1250/54.30	13/0.34	0/0	262/4.30	3/0.07	3970/111.75	0/0	0.2	0.77	13	8180	3025	47	Na-Ca Cl
- 8D2	12-10-57	66	7.2	3077	311/15.50	72/5.90	140/6.50	6.6/0.17	0/0	134/2.20	0/0	920/25.91	0/0	0	0.47	30	1594	1070	23	Ca Cl
- 8P1	10- 4-63	68	7.8	6750	265/13.22	111/9.10	999/43.46	10/0.26	0/0	261/4.28	1.4/0.03	2120/59.78	31/0.50	0.3	1.4	25	4590	1116	66	Na Cl
-17E2	7-11-63	69	7.4	9200	556/27.75	159/13.05	1400/61.00	13/0.34	0/0	225/3.68	8.2/0.17	3461/97.50	0/0	0.1	1.27	14	440	2040	60	Na Cl
-18A1	10-22-62	67	7.4	6700	553/27.60	102/8.40	800/34.80	13/0.34	0/0	155/2.55	13/0.27	2410/67.95	0/0	0.2	0.41	11	4464	1800	49	Na-Ca Cl
-18C3	4-27-60	70	7.1	18000	676/33.76	214/17.64	2870/124.80	34/0.86	0/0	441/7.24	0/0.01	6168/173.69	0/0	0	3.54	20	11500	2570	70	Na Cl

MINERAL ANALYSES OF GROUND WATERS
ANAHEIM BASIN, SANTA ANA GAP
(continued)

State well number	Date sampled	Temperature when sampled °F	pH	ECx10^6 at 25° C	Constituents in parts per million / equivalents per million									Parts per million					Percent Na	Character
					Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	B	SiO_2	Total dissolved solids	Total hardness ($CaCO_3$)		
TALBERT AQUIFER (continued)																				
6S/10W-18K7	4-23-63	68	7.5	14050	760 / 38.0	452 / 37.2	3312 / 144.0	47 / 1.20	0 / 0	549 / 9.00	0 / 0	7400 / 209.0	5.0 / 0.08	0.2	2.3	19	13150	3760	65	Na Cl
-18P1	4-23-63	68	7.6	14150	416 / 20.80	384 / 31.60	4139 / 180.0	43 / 1.10	0 / 0	552 / 9.05	0 / 0	7854 / 221.5	84 / 1.35	0.9	5.2	16	13666	2620	77	Na Cl
6S/11W- 1J6	10- 2-63	67	10.5	7510	928 / 46.31	11 / 0.89	612 / 26.62	17 / 0.44	12 / 0.40	0 / 0	203 / 4.22	2400 / 67.68	3.7 / 0.06	0.2	0.03	9	5101	2360	36	Ca Cl
- 1Q2	10- 8-63	66	7.5	10400	1010 / 50.40	181 / 14.90	1200 / 52.17	15 / 0.40	0 / 0	146 / 2.40	471 / 9.80	3716 / 104.80	0 / 0	0.1	0.18	16	9178	3265	44	Na-Ca Cl
-12B2	10- 8-63	65	7.3	10900	729 / 36.40	195 / 16.00	1500 / 65.22	15 / 0.40	0 / 0	183 / 3.00	459 / 9.57	3723 / 105.00	0 / 0	0.1	0.21	13	8422	2620	55	Na Cl
-13C2	10-22-62	66	7.2	9600	1170 / 58.50	174 / 14.25	1025 / 44.55	15 / 0.40	0 / 0	207 / 3.40	237 / 4.95	3910 / 110.25	0 / 0	0.2	0.20	11	8262	3637	38	Ca-Na Cl
-13D1	4-23-63	70	8.3	19650	1122 / 56.00	552 / 45.40	3008 / 130.8	27 / 0.70	0 / 0	18 / 0.3	706 / 14.7	7730 / 218.0	7.4 / 0.12	0.3	0.70	1	14266	5070	56	Na Cl
-13G2	3- 2-59	68	7.8	11120	473 / 23.60	209 / 17.20	1590 / 69.17	23 / 0.59	0 / 0	317 / 5.20	256 / 5.34	3610 / 101.80	0 / 0	0.3	0.90	20	8148	2040	62	Na Cl

APPENDIX E

AQUIFER TESTS

APPENDIX E

AQUIFER TESTS - SUMMARY SHEET

	Observation Well	Pumping Well	Distance between wells, r, (feet)	Type of Test	Aquifer Data: Aquifer Thickness, m (feet): Perforated Interval	Aquifer Data: Aquifer Thickness, m (feet): Total Aquifer Thickness	Aquifer Data: Aquifer Thickness, m (feet): Effective Aquifer Thickness	Aquifer Data: Coefficients: Permeability, P (gpd/ft^2)	Aquifer Data: Coefficients: Transmissibility, T (gpd/ft)	Aquifer Data: Coefficients: Storage S	Overlying Aquiclude: Coefficient of Permeability, P' (gpd/ft^2)	Overlying Aquiclude: Thickness m' (feet)	Aquifer Tested
1	6S/10W-8D9	6S/10W-8D8	367	Drawdown	38	48	38	2,220	84,300	4.64×10^{-4}	1.1 to 4 7	10 to 43	Talbert
2	6S/10W-17E2	6S/10W-17E2	--	Recovery	10	37	37	2,240	82,800	---	---	---	Talbert
3	6S/11W-13F4	6S/11W-13F4	--	Recovery	20	24	24	2,900	70,000	---	---	---	Talbert
4	5S/11W-36P1	5S/11W-36P3	802	Drawdown	not available	71	71	1,000	71,200	3.62×10^{-4}	20.16	48	Alpha
5	5S/10W-33C3	5S/10W-33C2	250	Drawdown	35	75	75	1,140	85,200	---	---	---	Merged Omicron & Upper Rho
6	5S/10W-33C3	5S/10W-33C2	250	Drawdown	35	75	75	1,000	75,300	3.5×10^{-4}	---	---	Merged Omicron & Upper Rho
7	6S/10W-6D2	6S/10W-6D2	--	Recovery	19	23	23	1,470	33,900	---	---	---	Lambda
8	6S/11W-1J5	6S/10W-6D2	1,870	Drawdown	21	31	23	1,470	33,700	0.8×10^{-4}	0.144	15	Lambda
9	6S/10W-6N2	6S/10W-6N2	--	Recovery	27	52	27	550	14,900	---	---	---	Main
10	6S/11W-1J4	6S/10W-6N2	1,837	Drawdown	32	50	32	410	13,000	1.15×10^{-4}	0.007	12	Main
11	6S/10W-8B3	6S/10W-8B3	--	Recovery	40	47	47	260	12,400	---	---	---	Main
12	6S/10W-8B3	6S/10W-8B3	--	Drawdown	40	47	47	350	14,000	---	---	---	Main
13	6S/10W-8C2	6S/10W-8B3	1,204	Drawdown	35	35	35	710	24,900	---	---	---	Main
14	6S/10W-8C2	6S/10W-8B3	1,204	Drawdown	35	35	35	570	20,100	1.34×10^{-4}	---	---	Main
15	6S/11W-1A3	6S/11W-1B2	934	Drawdown	50	185	100	1,080	108,000	2.12×10^{-4}	11.15	40	Main

APPENDIX E

AQUIFER TESTS

Aquifer	Probable average permeability, P (gpd/ft^2)	Estimated range of permeability, P (gpd/ft^2)
Talbert	2,200	1900-2500
Alpha I	1,600	1000-2000
Alpha II	1,900	1500-2200
Alpha III	1,900	1500-2200
Beta I	1,400	900-1900
Beta II	1,400	900-1900
Beta III	950	500-1400
Lambda	1,300	1000-1600
Omicron and Upper Rho	900	600-1200
Lower Rho and Main	650	300-1100
"Pico"	---	200- 300

APPENDIX F

PHYSICAL CHARACTERISTICS OF SEA-WATER INTRUSION AND MECHANICS OF SEA-WATER BARRIERS

APPENDIX F

PHYSICAL CHARACTERISTICS OF SEA-WATER INTRUSION AND MECHANICS OF SEA-WATER BARRIERS

Intrusion of sea water into aquifers and the design and construction of a barrier to repel that intrusion are governed by physical laws which are relatively simple in theory but difficult to apply because of inherent complexities of ground water basins. Physical characteristics of sea-water intrusion and the mechanics of various types of barriers are presented below.

Physical Characteristics of Sea-Water Intrusion

Two fundamental conditions must exist before a ground water basin can be intruded by sea water. First, the water-bearing materials forming the basin must be in hydraulic continuity with the ocean, and second, the normal seaward ground water gradient must be reversed or, at least, must be too flat to counteract the greater density of sea water. A discussion of these conditions and the physical laws governing sea-water intrusion occurrence and behavior follows.

Geologic Conditions

Ground water supplies in coastal basins in California are stored mainly in the larger alluvium-filled valleys. These valley-fill areas, of variable depth, are composed of unconsolidated alluvial fan, floodplain, and shallow marine deposits. These deposits extend to many hundreds of feet below sea level along the coast, and may extend for some distance beneath the floor of the Pacific Ocean.

Geologic evidence indicates that the water-bearing deposits along the seaward margins of these coastal ground water basins either may be in direct contact with the ocean floor at the shoreline, or may extend beneath the floor as confined pressure aquifers in contact with sea water at some distance offshore.

Hydraulic Conditions

Sea-water intrusion can occur only when the pressure head of sea water exceeds that of the fresh ground water, a condition which usually results when ground water levels are lowered to or below sea level by excessive pumping of wells. When the hydraulic gradient within a coastal basin slopes seaward, ground water is moving toward the ocean; conversely, when the slope is reversed, sea water is moving landward. It should be noted that under extremely small seaward gradients of the fresh water, both conditions can exist simultaneously. In practice, the slope of the hydraulic gradient is established from measurements of depth to water in observation wells.

Fresh Water-Salt Water Relationships

Fresh water weighs less than sea water. Therefore, when the two come in contact within a permeable formation, the lighter fresh water tends to float on the heavier sea water.

This phenomenon may be demonstrated by a simple laboratory apparatus in which a tube containing loose sand is partially immersed in ocean water and then filled from the top with fresh water. Under these idealized conditions, the fresh water displaces ocean water from the sand and floats upon it much as a solid buoyant object floats on water. The presence of the sand greatly impedes diffusion of the two liquids which would otherwise occur almost instantaneously.

The floating body of fresh water in this example conforms to Archimedes law of buoyancy which states that any floating object will displace its own weight of the medium in which it floats. This principle, as applied to relationships between fresh and sea water in ground water, is commonly known as the Ghyben-Herzberg Principle. It was described by Badon Ghyben in 1869, and applied to water supply problems by Bairat Herzberg in 1901.

Because sea water weighs 1.025 times as much as fresh water, the relationship between water table elevation above sea level (h) and depth to sea-water interface (H) may be developed by simple algebra as follows:

$$(H + h) = 1.025H \qquad \text{(Equation F-1)}$$

$$h = 1.025H-H$$

$$h = H(1.025-1)$$

$$h = 0.025H$$

$$h = \frac{1}{40} H$$

This equation indicates that a body of fresh water, floating upon sea water within a porous medium, adjusts in elevation until the depth of its lower surface, measured below sea level datum, is 40 times the height of its upper surface above this datum. Thus the floating body of fresh water assumes a shape such that its depth below sea level is everywhere 40 times its surface elevation above sea level.

The minimum elevation of the freshwater table required to prevent sea-water intrusion is determined by this principle. Theoretically, an intruding saline wedge can be held in a stationary position, or in equilibrium with the fresh water body, by maintaining the fresh water table at the proper elevation above mean sea level.

Figure F-1 shows an idealized section through a pressure aquifer subject to sea-water intrusion. B represents the distance below sea level to the lowest level which must be protected. M represents the thickness of a confined aquifer, L is the length of the sea-water wedge and q represents flow.

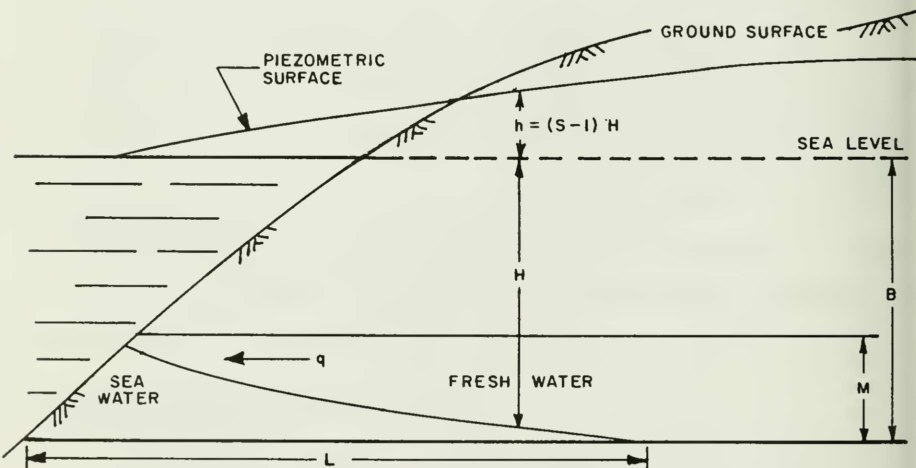


Figure F-1. Schema of a section through a confined aquifer

Under equilibrium conditions, there is no energy gradient within the saline wedge to provide movement. The pressure at a point on the saline water-fresh water interface is equivalent to that produced by a column of sea water extending up to sea level. To produce the same pressure on the fresh water side of the interface, a similar fresh water column -- because of the lower density of fresh water -- must extend above sea level. This distance above sea level (h on Figure F-1) is equal to (S-1) H, where S is the specific gravity of sea water and H is the depth below sea level to the interface at the same point.

The theoretical sea-water front assumes the shape of an inclined surface which always slopes landward, and which advances or recedes in response to changes in the hydraulic gradient. Because of its shape, this prism of ocean water has been called the sea-water wedge. Figure F-2 depicts a diagrammatic section through a coastal basin for an unconfined aquifer showing the shape of the wedge and its movement under various conditions.

Advance and retreat of the wedge commence at the toe, the position of the upper end of the interface remaining fixed at the shoreline until all fresh water near the coast is depleted to sea level, at which time the upper end of the interface commences its advance and the entire wedge moves as a body. If, on its landward advance, the toe of the wedge extends into a water table depression, an upwelling of sea water occurs. The configuration of this upwelling conforms to the dictates of the preceding equation (equation F-1). Where the depression is conical, as in the depression created by a pumping well, the upwelling of saline waters assumes the shape of an image cone, the surface of which theoretically becomes 40 times as high from the original interface as the depth to the pumping depression surface from the original water surface.

The sea-water wedge also forms in pressure aquifers, as indicated in the schematic illustrations of Figure F-3. By reasoning similar to that developed in the preceding paragraphs, it can be demonstrated that the relationship $H = 40h$ also holds true for pressure conditions.

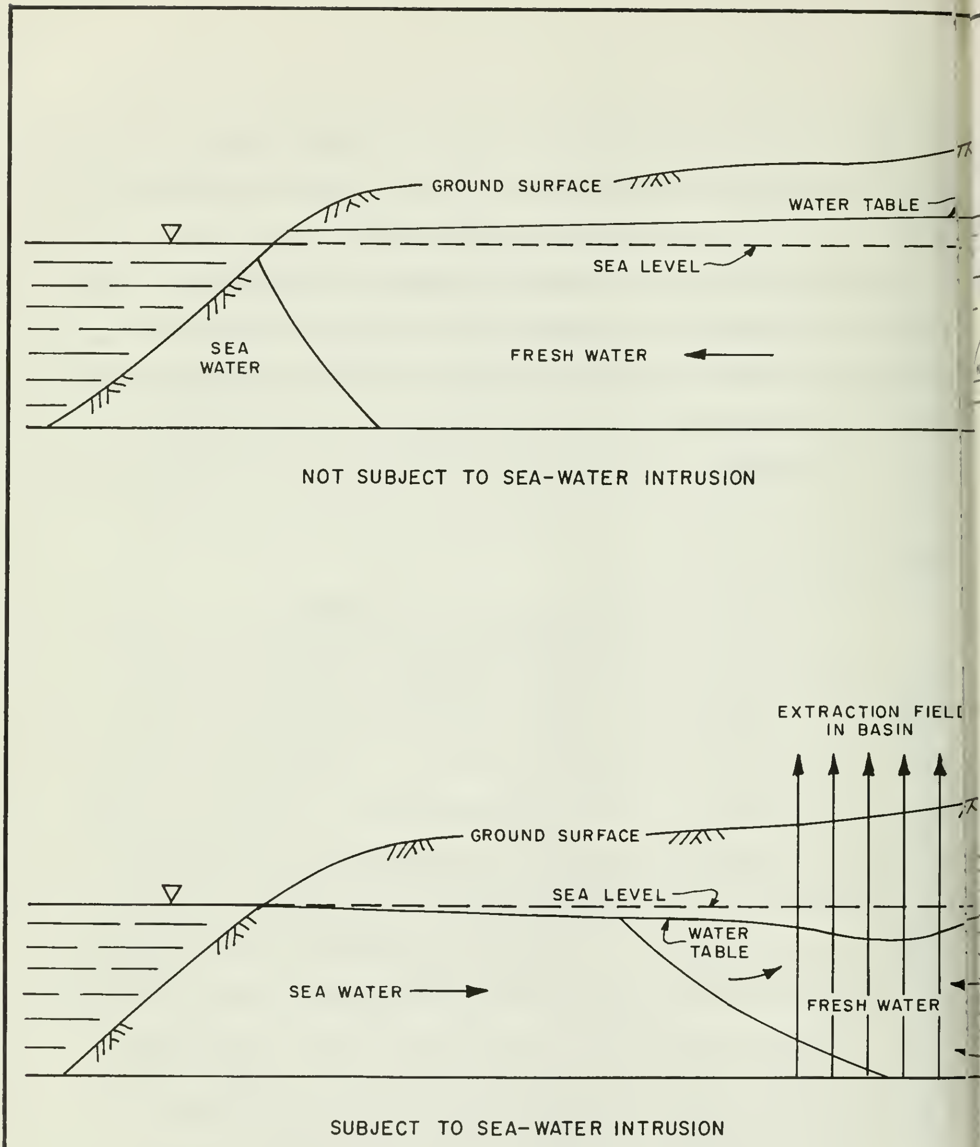
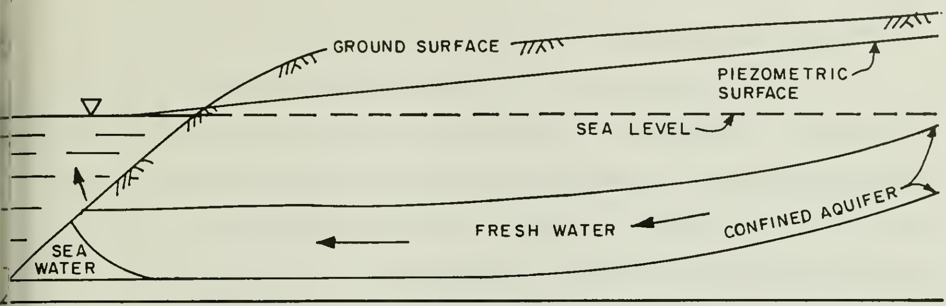
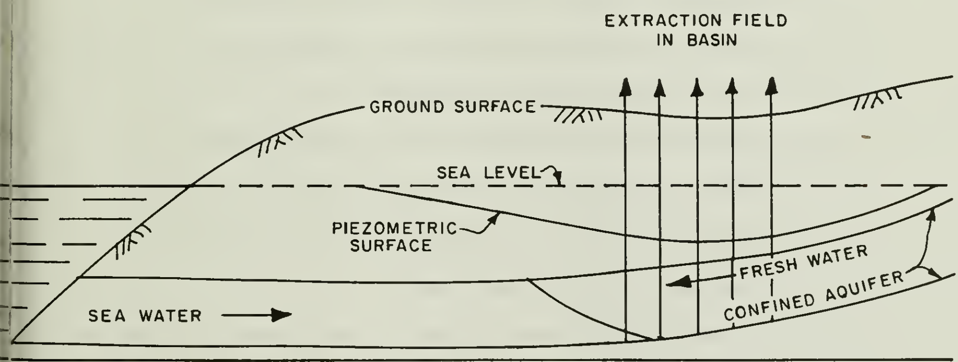


Figure F-2—HYDROLOGIC CONDITIONS IN AN UNCONFINED GROUND WATER BASIN



NOT SUBJECT TO SEA-WATER INTRUSION



SUBJECT TO SEA-WATER INTRUSION

Figure F-3— CONDITIONS IN A CONFINED GROUND WATER BASIN IN CONTINUITY WITH THE OCEAN

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Other Causes of Increased Ground Water Salinity

An increase in the salinity of ground water within a coastal basin does not necessarily establish the existence of sea-water intrusion. Such increases may be attributable entirely or in part to other factors. Some of the more significant causes of ground water degradation, other than sea-water intrusion, are the following:

1. Use and reuse of ground water, without sufficient outflow. (May result in adverse salt balance.)
2. Lateral or upward migration of brines or degraded waters contained in the formations flanking or underlying the ground water basin.
3. Downward seepage of sewage or industrial waste.
4. Downward seepage of mineralized surface waters from streams, lakes, and lagoons.
5. Migration of saline water from one water-bearing zone to another, either through natural breaks in impermeable layers or through defective, improperly constructed, or abandoned wells.

It is sometimes difficult to fix the true causes for rises in salinity of ground water. In some instances, chemical analyses and the ratios of certain constituent ions may prove helpful in identifying sea water. However, it is to be noted that, with present knowledge, distinguishing sea water from certain oil field brines or connate waters by means of chemical analyses is exceedingly difficult.

Mechanics of Sea-Water Intrusion Barriers

Six principal methods for the prevention and control of sea-water intrusion exist. These are:

1. Raising of ground water levels to or above sea level by controlling the areal pattern of pumping draft.
2. Direct artificial surface recharge of overdrawn aquifers to maintain ground water levels at or above sea level.
3. Maintenance of a freshwater ridge above sea level along the coast.
4. Development of a pumping trough adjacent to the ocean.
5. Combination freshwater ridge and pumping trough adjacent to the ocean.
6. Construction of static physical subsurface barriers.

It should be noted that implicit in all methods of control is the necessity for management of the ground waters of the basin by some agency. Assurance of an adequate water supply to support the economy of lands now dependent upon the local basin water supplies, without impairment, must be a primary consideration in any program for control of sea-water intrusion. This may involve importation of supplemental water from nontributary sources, or additional conservation of local supplies, or both. Maintaining or, if possible, increasing conservation of locally available water resources generally would be a major factor in the formulation and application of a program for control of sea-water intrusion.

The objectives of any control program should be to prevent further encroachment and, if possible, to reduce the area already affected by sea-water intrusion. A comprehensive engineering, geologic, hydrologic, and water quality investigation must be undertaken to obtain the information necessary for a proper determination of the method or methods of control to be used.

A more detailed description of each of the six methods follows:

Controlling Pumping Patterns

This method requires that the pumping draft be altered sufficiently, either by reduction in extractions, by rearrangement of areal pattern of pumping, or both, so that ground water levels will rise to or above sea level and be maintained there, except possibly for infrequent periods of short duration. A seaward hydraulic gradient must be established and maintained, resulting in partial recovery from sea-water intrusion as shown on Figure F-4.

Although it is manifest that reduction in pumping draft would tend to effect a rise in ground water levels, additional comment is warranted regarding effects of rearrangement of the pumping pattern. If the location of major withdrawals is transferred from the coastal segment of a basin to an area further inland, the landward hydraulic gradient on the ocean side of the trough would be flattened, and the seaward gradient inland from the trough would be increased. Such a condition would tend to slow or halt the inflow of saline water.

Direct Artificial Surface Recharge

This method requires that ground water levels in the overdrawn aquifers be raised and maintained above sea level by artificial recharge, utilizing surface spreading, injection wells, or both. In most instances, supplemental water from nontributary sources would be necessary, although for some basins, additional conservation of tributary runoff could be

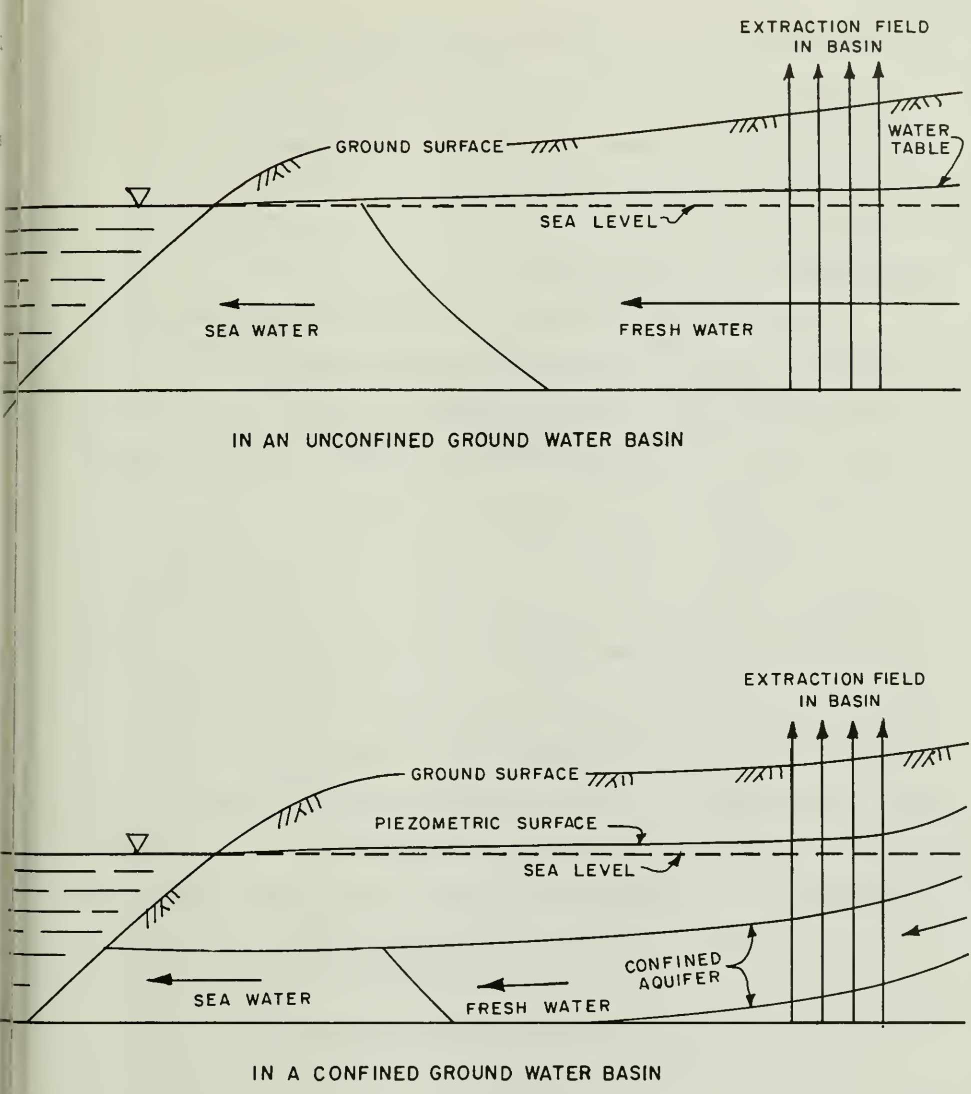


Figure F-4—PARTIAL RECOVERY FROM INTRUDED CONDITION

ARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966 achieved by providing sufficient upstream regulatory storage to permit artificial recharge. Rearrangement of the pattern of pumping draft might, under certain circumstances, facilitate use of this method and reduce the total cost involved.

Maintenance of a Freshwater Ridge

This method would require the continuous maintainance of a freshwater ridge in the principal water-bearing deposits along the coast through the application of water by surface spreading or injection wells or both. Effects of a freshwater ridge or mound on sea-water intrusion are shown on Figure F-5 for confined and unconfined aquifers.

The actual formation of a ridge along the coastal segment of a ground water basin by the use of injection wells or surface spreading, or a combination of both methods, would depend on whether free ground water or pressure conditions exist, as determined by detailed engineering and geologic investigation. In basins where free ground water conditions exist along the site of the proposed ridge, a mound of more or less uniform height could probably be maintained by continuous application of water in spreading grounds. In ground water basins where pressure conditions exist and injection wells are utilized, the ridge would consist of a series of peaks and saddles in the piezometric surface. In either case, the required elevation of the ridges and saddles above sea level would be determined by the distance of the base of the aquifer below sea level, its transmissibility, and the existing hydraulic gradient in the aquifer.

The total injection rate along the recharge line must be equal to the sum of the freshwater waste to the ocean necessary to maintain the

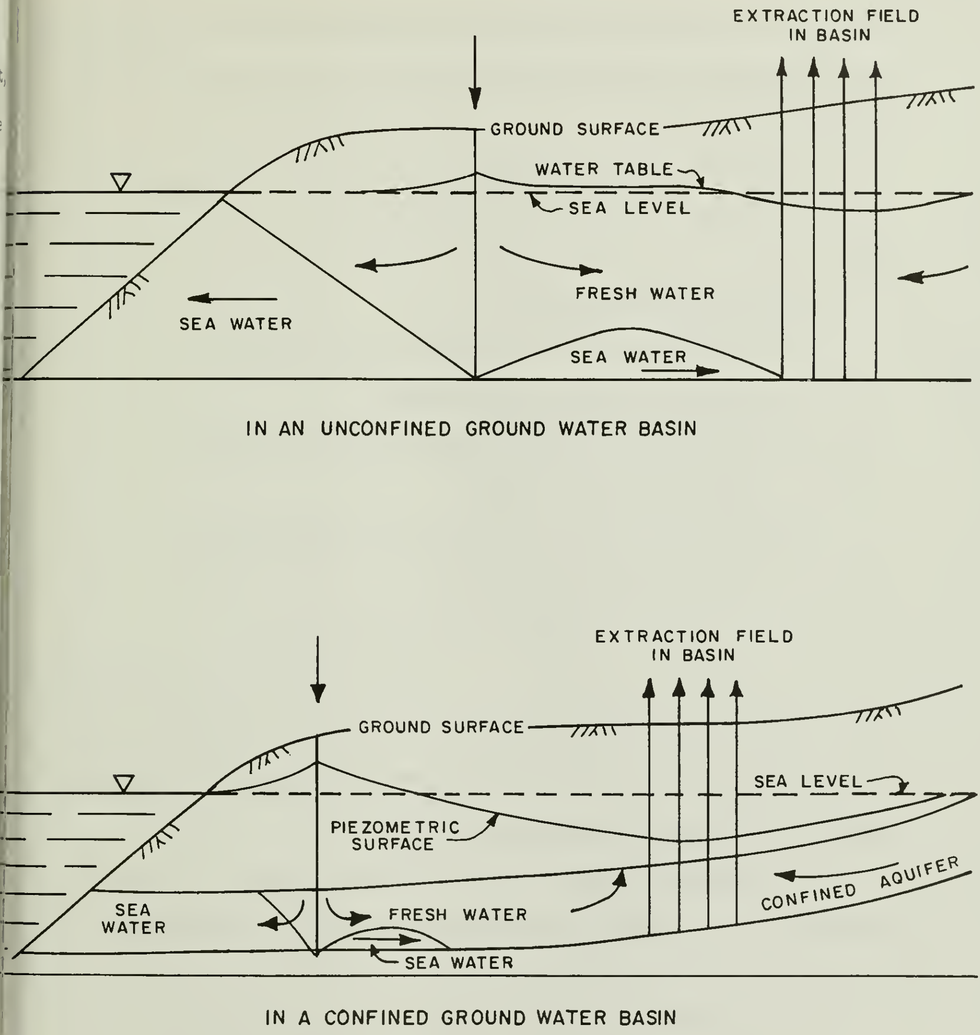


Figure F-5— HYDROLOGIC CONDITIONS WITH AN INJECTION RIDGE SEA-WATER BARRIER

...TMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966 position of the sea-water wedge and the overdraft of the basin originally being satisfied by landward flow of sea water. This relationship may be expressed as follows:

$$Q = 1/2\ (S - 1)\ \frac{M}{L}\ T + iT \qquad \text{(Equation F-2)}$$

where:

Q = total injection rate,

i = landward hydraulic gradient prior to injection,

S = specific gravity of sea water,

M = thickness of aquifer, down to the lowest depth which must be protected,

L = length of sea-water wedge, from ocean outlet to the toe (see Figure F-1),

T = aquifer transmissibility for 100 percent hydraulic gradient.

This was determined through model studies of sea-water intrusion into a confined aquifer, conducted by the Sanitary Engineering Research Laboratory, University of California, Berkeley.

The West Coast Basin Experimental Project conducted by the Los Angeles County Flood Control District established the following results:

1. Injection of water through wells can pressurize a confined aquifer along a coastal reach, thereby reversing any preexisting landward gradient and preventing further sea-water intrusion.
2. Loss of fresh water to the ocean will be small in relation to the total quantity of water injected.

3. An aquifer containing water already degraded by sea-water intrusion can be made usable by injection of water through wells.

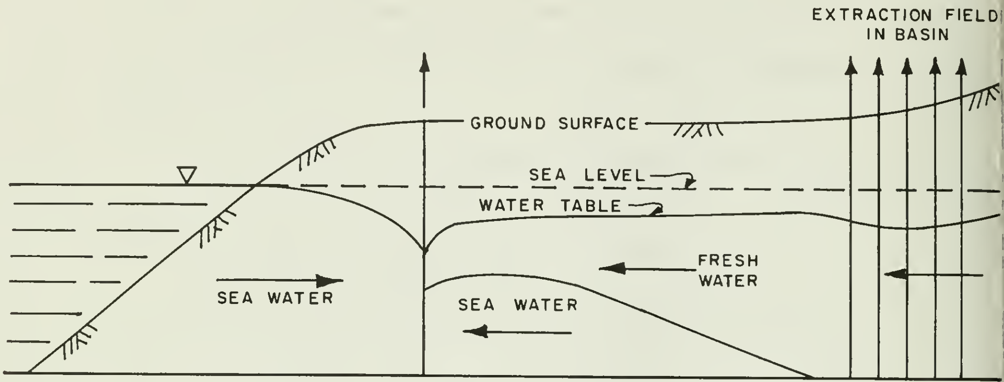
4. A recharge rate of 6 second-feet per mile, effected by injection through wells spaced 500 feet apart, is adequate to establish a pressure ridge 2 to 3 feet above sea level. This is sufficient to halt the inland flow of sea water.

5. Water for injection must be compatible chemically with native waters and must be treated to avoid clogging the aquifer. Chlorine dosages of between 5 to 10 parts per million are necessary to prevent slime growth and maintain transmissibility.

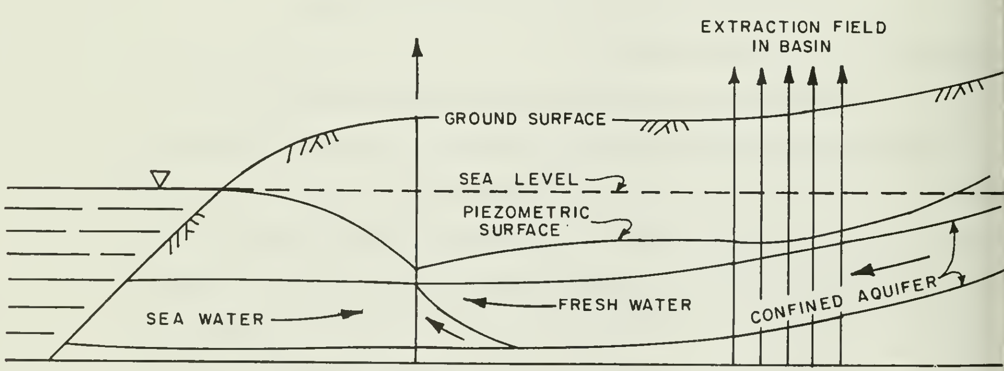
Pumping Trough or Extraction Barrier

Development of an extraction barrier would require maintaining a continuous pumping trough adjacent to the ocean. Trough elevations below the lowest water level in the basin are necessary to form the desired seaward hydraulic gradient. The distance trough elevations must be drawn down below the lowest water level in the basin is dependent upon the distance of the base of the aquifer to be protected below sea level and the density of sea water. Under the influence of the resulting gradient, sea water would be pulled a short distance from the ocean to the trough, and fresh water in the basin would move seaward toward the trough. These conditions are depicted on Figure F-6.

From sea-water intrusion model studies conducted by the Sanitary Engineering Research Laboratory at the University of California, Berkeley,



IN AN UNCONFINED GROUND WATER BASIN



IN A CONFINED GROUND WATER BASIN

Figure F-6—HYDROLOGIC CONDITIONS WITH AN EXTRACTION TYPE SEA-WATER BARRIER

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966

it was concluded that intruding sea water can be intercepted by establishment of a pumping trough, created by a line of pumping wells parallel to the coast. This method would provide no replenishment to a coastal basin, but the loss of fresh water wasted to the ocean need be no greater than that which would occur with a pressure ridge established through the use of injection wells.

Combination Injection-Extraction Barrier

An additional dynamic barrier is a combination injection ridge and pumping trough as shown on Figure F-7 for both unconfined and confined ground water basins. The pumping trough would be operated nearest the ocean with the injection ridge located further inland. A combination barrier would require about one-third as much extraction to achieve the same effect as a pumping trough alone, and also would require slightly smaller quantities of injected fresh water to achieve the effect of an injection ridge alone.

Static Physical Subsurface Barriers

This method involves the establishment of a subsurface barrier to reduce the permeability of the water-bearing deposits sufficiently to prevent the inflow of sea water into the freshwater strata. This reduction in permeability could be achieved by the construction of a subsurface barrier composed of sheet piling, puddled clay cutoff wall, or some other form of physical structure. Emulsified asphalt, cement grout, bentonite, silica gel, calcium acrylate, plastics, and other materials might be injected to form a vertical zone of reduced permeability which would retard or prevent intrusion of sea water into the freshwater portion of the aquifer.

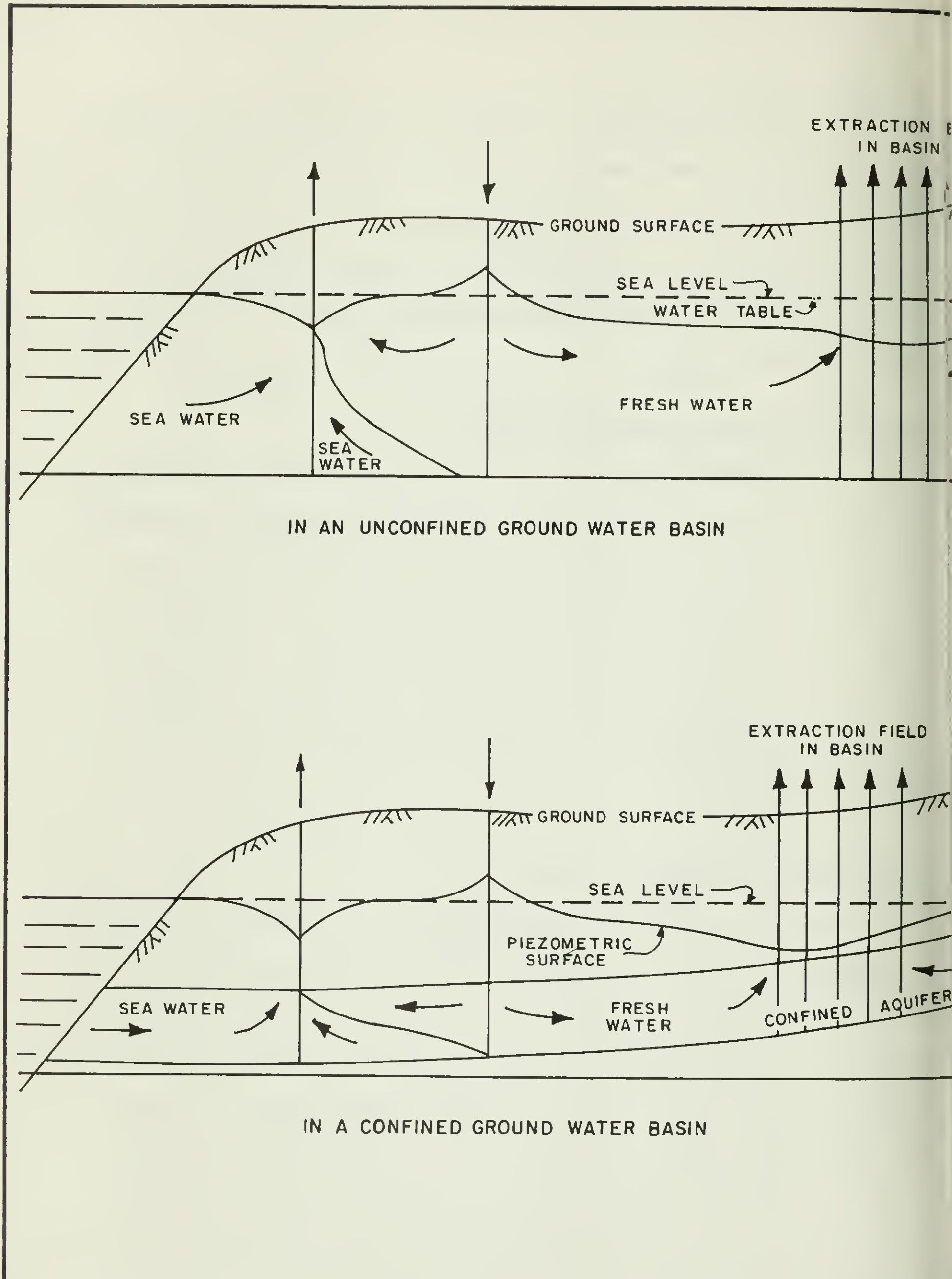


Figure F-7—HYDROLOGIC CONDITIONS WITH A COMBINATION INJECTION-EXTRACTION SEA-WATER BARRIER

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1966

Implementation of this method of control would require knowledge of the location, extent, thickness, depth, and other physical characteristics of the water-bearing deposits.

Effects of a subsurface barrier on hydrologic conditions in a confined and unconfined aquifer are shown on Figure F-8. This type of barrier would allow inland water levels to be lowered, thus allowing ground water resources, storage capacity, and tributary surface runoff to be exploited to an optimum degree, increasing the yield of the basin.

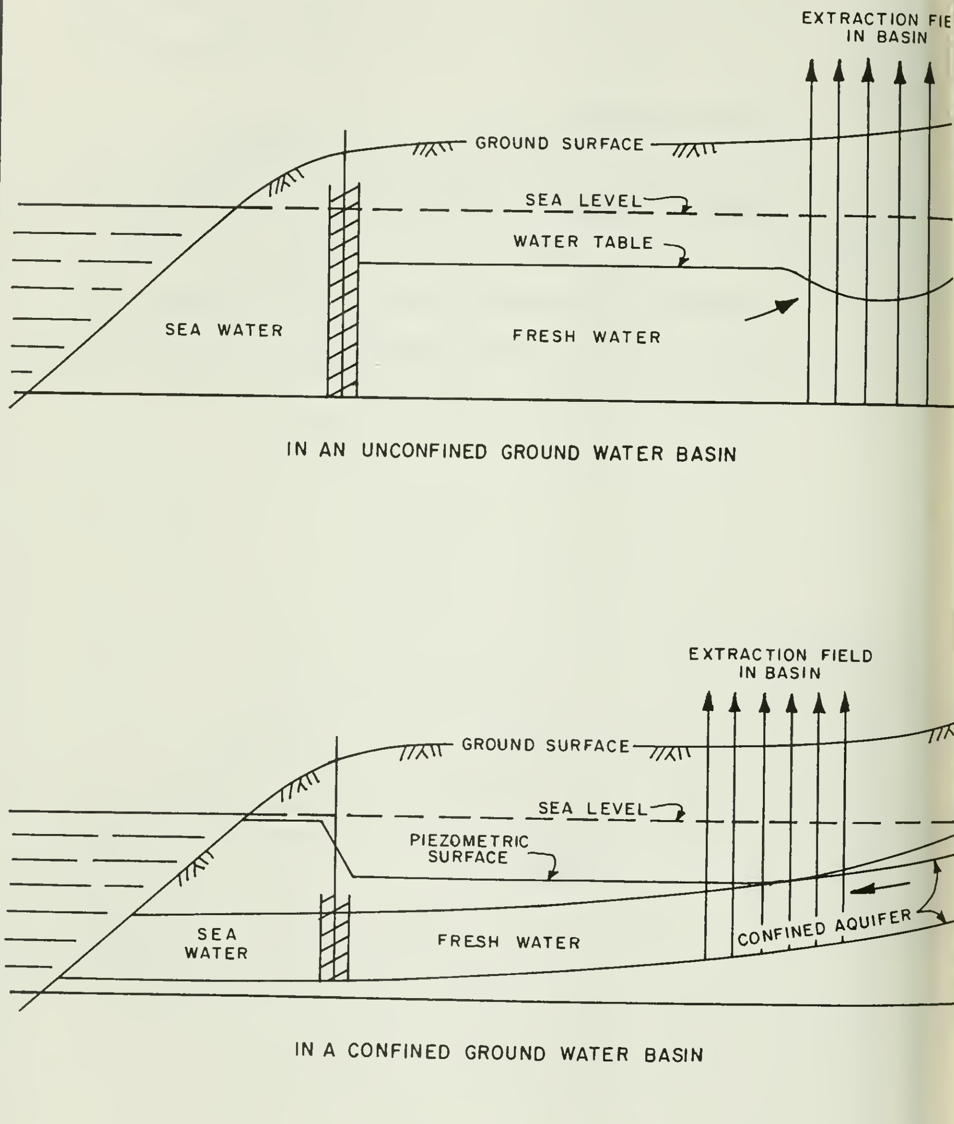


Figure F-8—HYDROLOGIC CONDITIONS WITH A STATIC OR PHYSICAL SEA-WATER BARRIER

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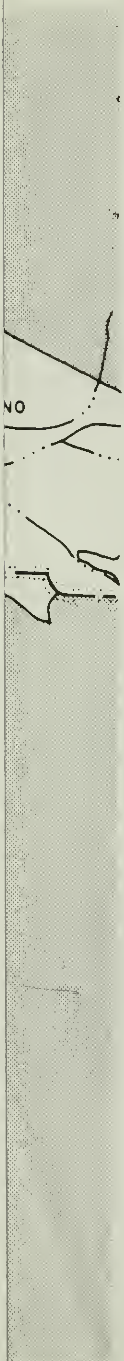
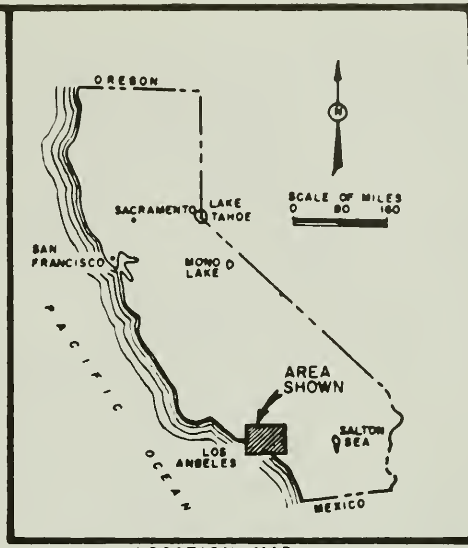




LOCATION MAP

LEGEND

UPLAND AND MOUNTAIN AREA

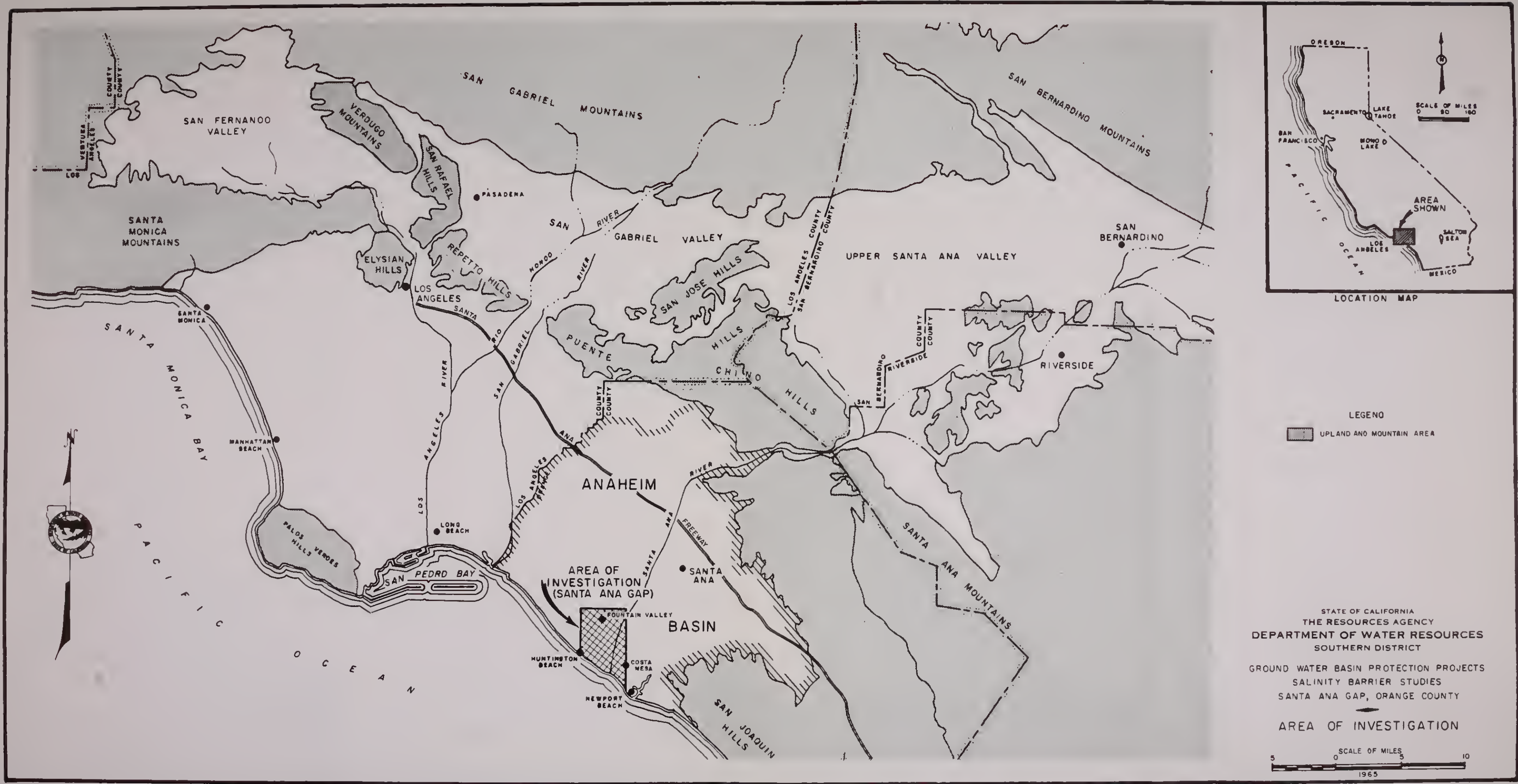
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

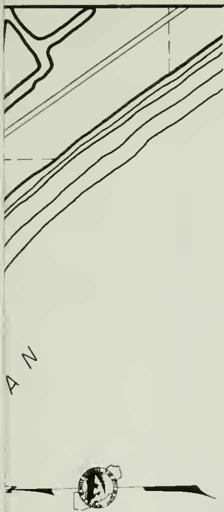
GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

AREA OF INVESTIGATION

SCALE OF MILES
5 0 5 10

1965


SAN GABRIEL MOUNTAINS
SAN BERNARDINO MOUNTAINS
SAN FERNANDO VALLEY
VERDUGO MOUNTAINS
SAN RAFAEL HILLS
PASADENA
SANTA MONICA MOUNTAINS
ELYSIAN HILLS
REPETTO HILLS
SAN GABRIEL VALLEY
SAN JOSE HILLS
UPPER SANTA ANA VALLEY
SAN BERNARDINO
LOS ANGELES
SANTA MONICA
PUENTE HILLS
CHINO HILLS
RIVERSIDE
SANTA MONICA BAY
MANHATTAN BEACH
ANAHEIM
LONG BEACH
PALOS VERDES HILLS
SAN PEDRO BAY
SANTA ANA
AREA OF INVESTIGATION (SANTA ANA GAP)
FOUNTAIN VALLEY
BASIN
HUNTINGTON BEACH
COSTA MESA
NEWPORT BEACH
SAN JOAQUIN HILLS
SANTA ANA MOUNTAINS
PACIFIC OCEAN
SANTA ANA FREEWAY
LOCATION MAP
OREGON
SACRAMENTO
LAKE TAHOE
SAN FRANCISCO
MONO LAKE
AREA SHOWN
LOS ANGELES
SALTON SEA
MEXICO
SCALE OF MILES 0 80 160
LEGEND
UPLAND AND MOUNTAIN AREA
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY
AREA OF INVESTIGATION
SCALE OF MILES
5 0 5 10
1965



LEGEND

A1
● LOCATION OF EXISTING WATER WELL

B2
LOCATION OF EXPLORATORY TEST WELLS

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

LOCATION OF EXISTING WATER WELLS

SCALE OF FEET
1000 0 1000 2000 3000

1965

LEGEND

A1 ● LOCATION OF EXISTING WATER WELL

B2 ✦ LOCATION OF EXPLORATORY TEST WELLS

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

LOCATION OF EXISTING WATER WELLS

SCALE OF FEET
1000 0 1000 2000 3000

1965

LEGEND

- ● SA-25 — LOCATION OF BACKFILLED EXPLORATORY TEST HOLE, SA-25 DENOTES DWR TEST HOLE NUMBER
- B2 ◉ (SA-11) — LOCATION OF EXPLORATORY WELL-1 PIEZOMETER, B2 DENOTES STATE WELL NUMBER (SA-11 DENOTES DWR TEST WELL NUMBER)
- Q7, 8 ◉ (OCWD T-3) — LOCATION OF EXPLORATORY WELL-2 PIEZOMETERS, Q7, 8 DENOTE STATE WELL NUMBERS (OCWD T-3 DENOTES ORANGE COUNTY WATER DISTRICT TEST WELL NUMBER)
- L 4,5,6 ◉ (SA-12) — LOCATION OF EXPLORATORY WELL-3 PIEZOMETERS, L4, 5, 6 DENOTE STATE WELL NUMBERS (SA-12 DENOTES DWR TEST WELL NUMBER)

STATE OF CALIFORNIA
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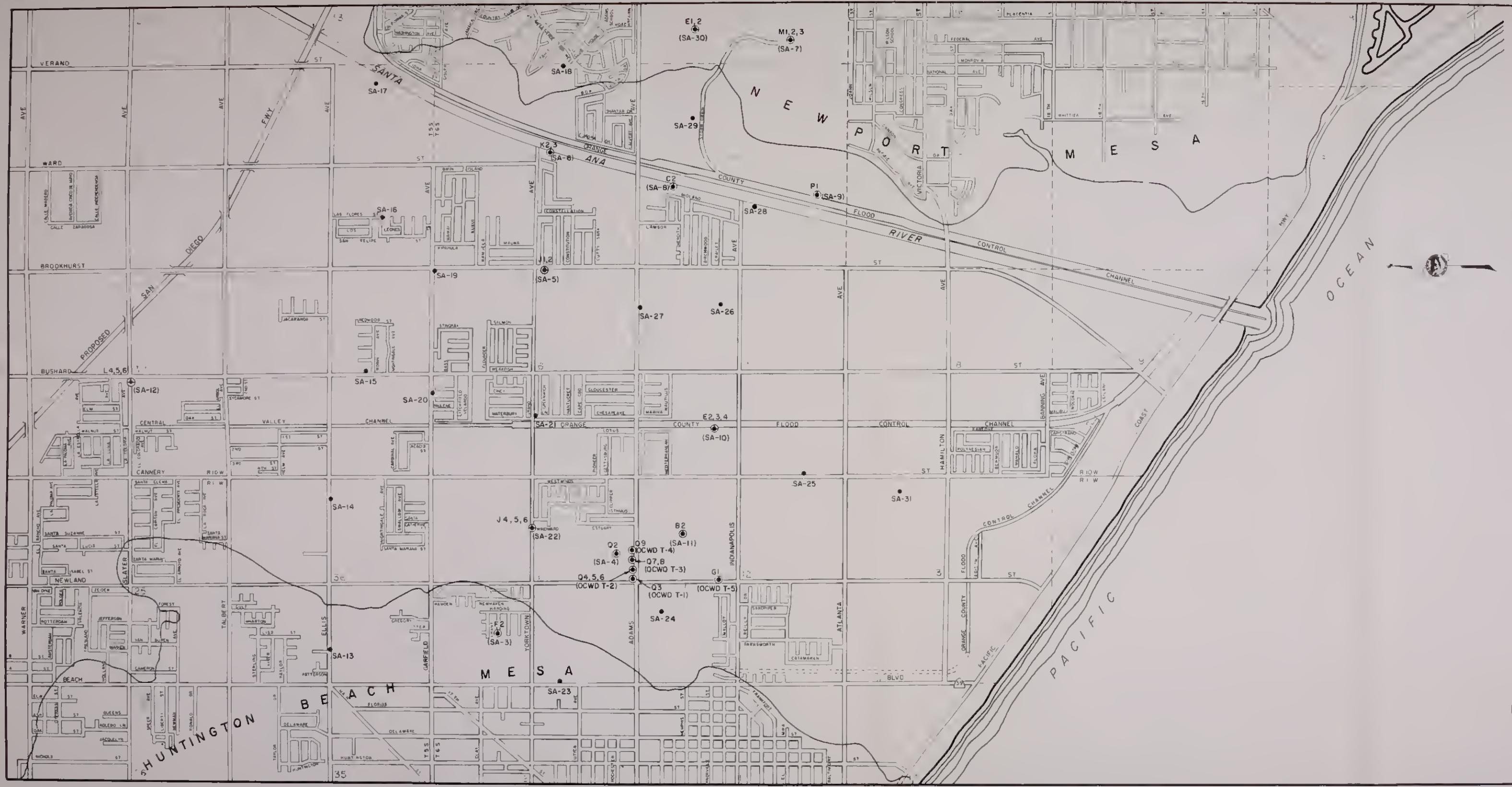
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

LOCATION OF EXPLORATORY TEST HOLES AND PIEZOMETERS

SCALE OF FEET
1000 0 1000 2000 3000

1965



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

LOCATION OF EXPLORATORY TEST HOLES AND PIEZOMETERS

LEGEND

RECENT		Qal	ALLUVIUM GRAVEL, SAND, SILT, AND CLAY
PLEISTOCENE	UPPER	Qpu	LAKEWOOD FORMATION CONTINENTAL AND MARINE GRAVEL, SAND, SILT, AND CLAY
PLEISTOCENE	LOWER	Qpl	SAN PEDRO FORMATION MARINE SAND, GRAVEL, SILT, AND CLAY
PLIOCENE / MIOCENE		Tu	MID-PLIOCENE UNDIFFERENTIATED SHALE AND SILTSTONE

CONTACT (DASHED WHERE APPROXIMATELY LOCATED)

U / D — FAULT (DASHED WHERE APPROXIMATELY LOCATED; U, UPTHROWN SIDE; D, DOWNTHROWN SIDE)

CONCEALED FAULT, SHOWING RELATIVE MOVEMENT

? ? ? — PROBABLE FAULT (DOTTED WHERE CONCEALED)

A A' — LINE OF GEOLOGIC SECTION. SECTIONS ARE SHOWN ON PLATES 5A THROUGH 5G.

LOCATION OF WELLS WITH SUBSURFACE GEOLOGIC DATA USED IN THIS REPORT

- ● G1 — WATER WELL WITH CONFIDENTIAL FILE DRILLER'S LOG
- ◑ B2 — WATER WELL WITH OPEN FILE DRILLER'S LOG
- ⊕ Rc — OIL WELL WITH ELECTRIC LOG
- ⦿ SA-3 — DWR EXPLORATORY TEST WELL OR TEST HOLE
- ⊕ T-1 — OCWD EXPLORATORY TEST WELL
- ○ 26 — SOIL BORING LOG

STATE OF CALIFORNIA
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SOUTHERN DISTRICT

GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

AREAL GEOLOGY

SCALE OF FEET

1000 0 1000 2000 3000

1965

LEGEND

QUATERNARY	PLEISTOCENE / RECENT	RECENT	Qal	ALLUVIUM GRAVEL, SAND, SILT, AND CLAY
	PLEISTOCENE	UPPER	Qpu	LAKEWOOD FORMATION CONTINENTAL AND MARINE GRAVEL, SAND, SILT AND CLAY
		LOWER	Qpl	SAN PEDRO FORMATION MARINE SAND, GRAVEL, SILT, AND CLAY
TERTIARY	PLIOCENE / MIOCENE		Tu	MIO-PLIOCENE UNDIFFERENTIATED SHALE AND SILTSTONE

CONTACT (DASHED WHERE APPROXIMATELY LOCATED)

FAULT (DASHED WHERE APPROXIMATELY LOCATED; U, UPTHROWN SIDE; D, DOWNTHROWN SIDE)

CONCEALED FAULT, SHOWING RELATIVE MOVEMENT

PROBABLE FAULT (DOTTED WHERE CONCEALED)

LINE OF GEOLOGIC SECTION. SECTIONS ARE SHOWN ON PLATES 5A THROUGH 5G

LOCATION OF WELLS WITH SUBSURFACE GEOLOGIC DATA USED IN THIS REPORT

- WATER WELL WITH CONFIDENTIAL FILE DRILLER'S LOG
- B2 WATER WELL WITH OPEN FILE DRILLER'S LOG
- Rc OIL WELL WITH ELECTRIC LOG
- SA-3 DWR EXPLORATORY TEST WELL OR TEST HOLE
- T-1 OCWD EXPLORATORY TEST WELL
- 26 SOIL BORING LOG

STATE OF CALIFORNIA
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DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

AREAL GEOLOGY

SCALE OF FEET
1000 0 1000 2000 3000

1965

LEGEND

APPROXIMATE AREA UNDERLAIN BY ORGANIC MATERIAL*

- 0.5 TO 5 FEET IN THICKNESS
- 5 TO 25 FEET IN THICKNESS
- 25 TO 60 FEET IN THICKNESS

APPROXIMATE AREA THOUGHT TO BE UNDERLAIN BY ORGANIC MATERIAL**

- GREATER THAN 5 FEET IN THICKNESS

NOTE *DETERMINED FROM WATER WELL DRILLER'S LOGS AND EXPLORATORY TEST HOLE DATA

**DETERMINED FROM VISUAL EVIDENCE OF MARKED SURFACE SUBSIDENCE

STATE OF CALIFORNIA.
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

LOCATION OF PEAT AND ORGANIC SOILS

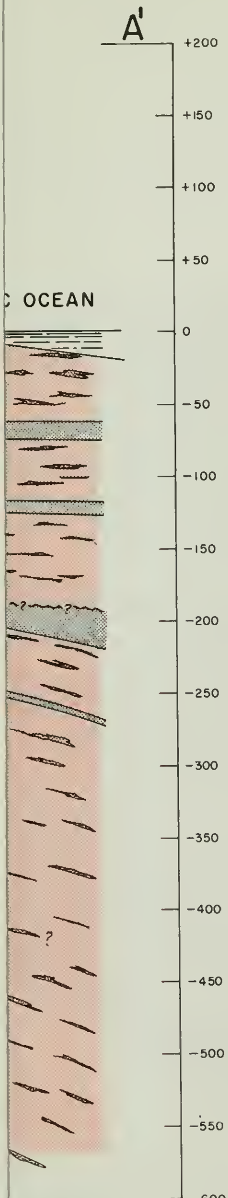
SCALE OF FEET

1000 0 1000 2000 3000

1965

PLATE 48


NEWPORT
MESA
HUNTINGTON
BEACH
MESA
PACIFIC
OCEAN
SANTA ANA RIVER FLOOD CONTROL CHANNEL
ORANGE COUNTY FLOOD CONTROL CHANNEL
CENTRAL VALLEY CHANNEL
PROPOSED SAN DIEGO FWY
COAST HWY
VERAND
WARD
BROOKHURST
BUSHARD
CANNERY
NEWLAND
BEACH BLVD
WARNER
SLATER
TALBERT
ELLIS
GARFIELD
YORKTOWN
ADAMS
INDIANAPOLIS
ATLANTA
HAMILTON
BANNING
VICTORIA
18 ST
R10W
R11W
T5S
T6S
LEGEND
APPROXIMATE AREA UNDERLAIN BY ORGANIC MATERIAL*
0.5 TO 5 FEET IN THICKNESS
5 TO 25 FEET IN THICKNESS
25 TO 60 FEET IN THICKNESS
APPROXIMATE AREA THOUGHT TO BE UNDERLAIN BY ORGANIC MATERIAL**
GREATER THAN 5 FEET IN THICKNESS
NOTE *DETERMINED FROM WATER WELL DRILLER'S LOGS AND EXPLORATORY TEST HOLE DATA
**DETERMINED FROM VISUAL EVIDENCE OF MARKED SURFACE SUBSIDENCE
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY
LOCATION OF PEAT AND ORGANIC SOILS
SCALE OF FEET
3000
1965



LEGEND

AOUIFER
SAND OR SAND AND CLAY

AOUICLUDE
CLAY, SILT, SANDY CLAY OR SANDY SILT

AOUIFER
SAND OR GRAVEL WITH CLAY OR SILT LENSES

AOUICLUDE
CLAY OR SILT WITH SAND OR GRAVEL LENSES

AOUIFER SALINITY
100-500 PPM CHLORIDE ION CONCENTRATION IN 1963

AOUIFER SALINITY
GREATER THAN 500 PPM CHLORIDE ION CONCENTION IN 1963

T | A FAULT
(LETTERS OENOTE RELATIVE MOVEMENT, T = TOWARO, A = AWAY)

UNCONFORMITY

SOURCES OF SUBSURFACE GEOLOGIC DATA

6S/10W-20Da
OIL WELL WITH ELECTRIC LOG
(OASHED WHERE LOG IS UNAVAILABE)

5S/10W-33D1
WATER WELL WITH DRILLERS LOG

SA-17
E | S
DWR EXLORATORY WELL WITH ELECTRIC AND LITHOLOGIC LOG
("E S" DENOTES LOCATION OF PALEONTOLOGICAL MARKER, ELPHIDIUM SPINATUM)

23
SOIL BORING LOG

NOTE: LOCATION OF GEOLOGIC SECTIONS ARE SHOWN ON PLATE 4

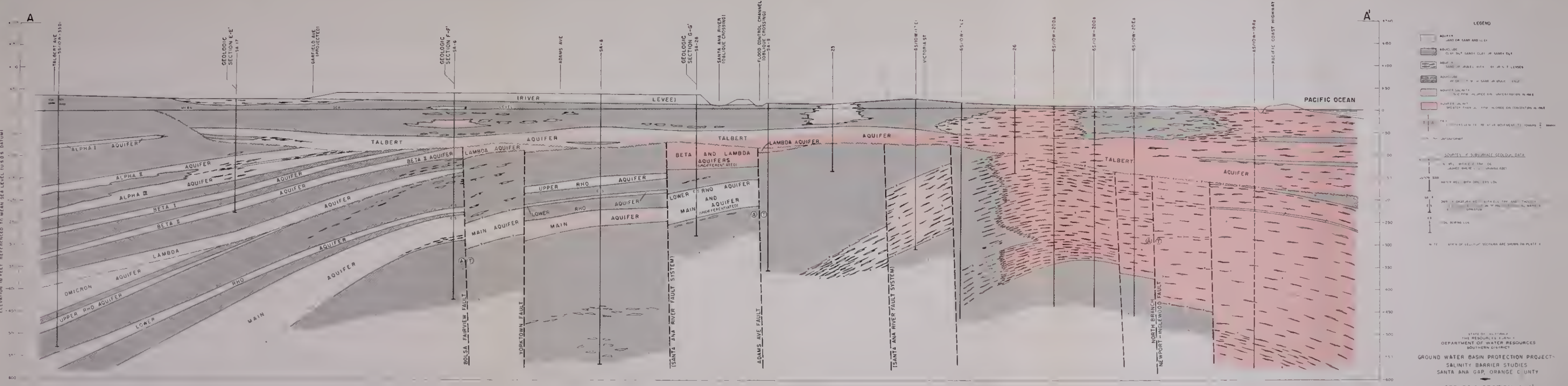
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

GEOLOGIC SECTION A-A'

HORIZONTAL SCALE OF FEET
500 0 500 1000 1500

1965

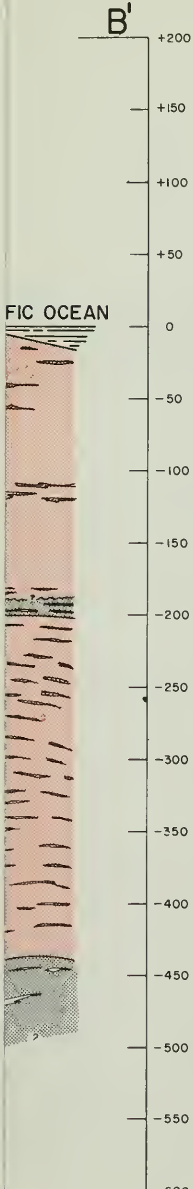


GEOLOGIC SECTION A-A'—ALONG THE SANTA ANA RIVER

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

GROUND WATER BASIN PROTECTION PROJECT
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

GEOLOGIC SECTION A-A'



LEGEND

AQUIFER
SAND OR SAND AND CLAY

AQUICLUDE
CLAY, SILT, SANDY CLAY OR SANDY SILT

AQUIFER
SAND OR GRAVEL WITH CLAY OR SILT LENSES

AQUICLUDE
CLAY OR SILT WITH SAND OR GRAVEL LENSES

AQUIFER SALINITY
100-500 PPM CHLORIDE ION CONCENTRATION IN 1963

AQUIFER SALINITY
GREATER THAN 500 PPM CHLORIDE ION CONCENTION IN 1963

T | A FAULT
(LETTERS DENOTE RELATIVE MOVEMENT, T = TOWARD, A = AWAY)

UNCONFORMITY

SOURCES OF SUBSURFACE GEOLOGIC DATA

6S/11W-13Ja
OIL WELL WITH ELECTRIC LOG
(DASHED WHERE LOG IS UNAVAILABE)

5S/10W-31F3
WATER WELL WITH DRILLERS LOG

SA-15
E S
DWR EXLORATORY WELL WITH ELECTRIC AND LITHOLOGIC LOG
("E S" DENOTES LOCATION OF PALEONTOLOGICAL MARKER, ELPHIDIUM SPINATUM)

NOTE: LOCATION OF GEOLOGIC SECTIONS ARE SHOWN ON PLATE 4

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

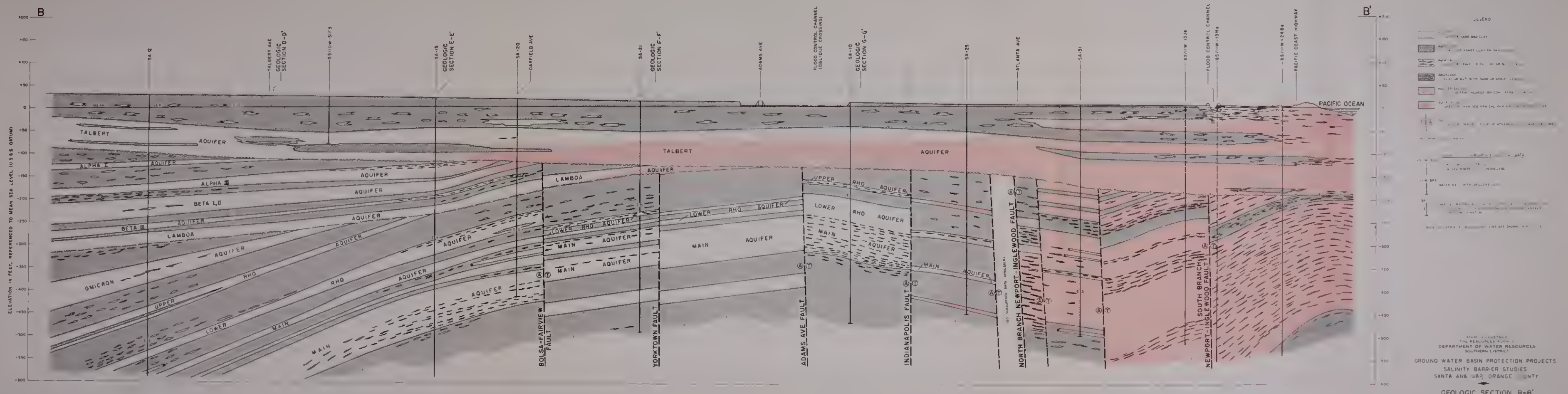
GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

GEOLOGIC SECTION B-B'

HORIZONTAL SCALE OF FEET
500 0 500 1000 1500

1965

PLATE 38

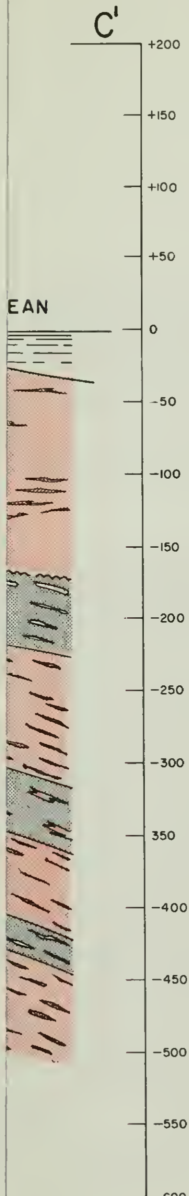


GEOLOGIC SECTION B-B' — ALONG BUSHARD AND CANNERY STREETS

DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

GEOLOGIC SECTION B-B'



LEGEND

AQUIFER
SAND OR SAND AND CLAY

AQUICLUDE
CLAY, SILT, SANDY CLAY OR SANDY SILT

AQUIFER
SAND OR GRAVEL WITH CLAY OR SILT LENSES

AQUICLUDE
CLAY OR SILT WITH SAND OR GRAVEL LENSES

AQUIFER SALINITY
100-500 PPM CHLORIDE ION CONCENTRATION IN 1963

AQUIFER SALINITY
GREATER THAN 500 PPM CHLORIDE ION CONCENTION IN 1963

T A FAULT
(LETTERS DENOTE RELATIVE MOVEMENT, T = TOWARD, A = AWAY)

UNCONFORMITY

SOURCES OF SUBSURFACE GEOLOGIC DATA

6S/11W-12Fb
OIL WELL WITH ELECTRIC LOG
(DASHED WHERE LOG IS UNAVAILABE)

5S/11W-25E2
WATER WELL WITH DRILLERS LOG

SA-13
E S
DWR EXLORATORY WELL WITH ELECTRIC AND LITHOLOGIC LOG.
("E S" DENOTES LOCATION OF PALEONTOLOGICAL MARKER, ELPHIDIUM SPINATUM)

NOTE: LOCATION OF GEOLOGIC SECTIONS ARE SHOWN ON PLATE 4

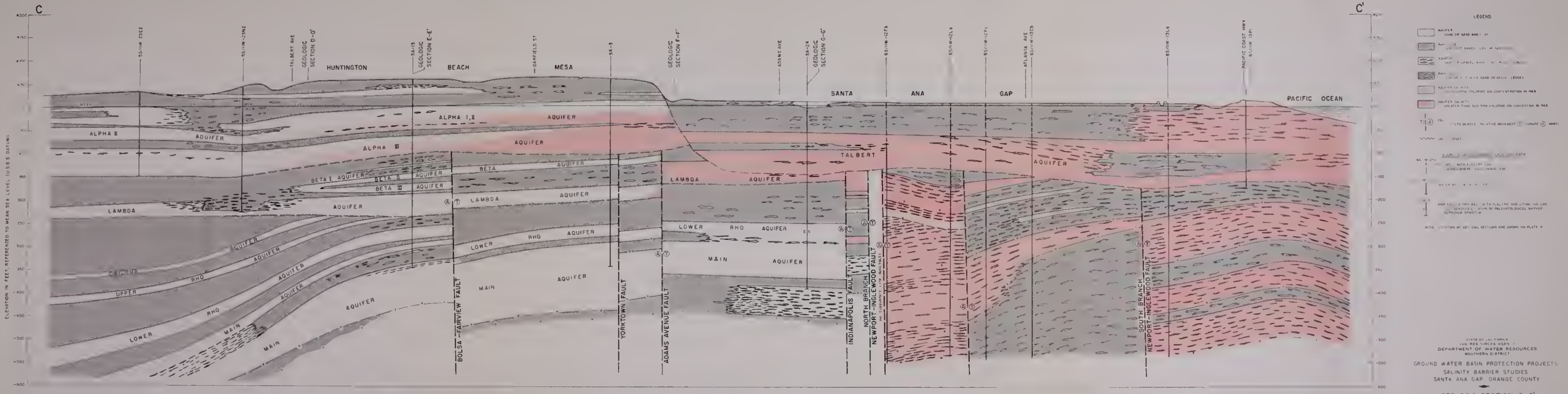
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

GEOLOGIC SECTION C-C'

HORIZONTAL SCALE OF FEET
500 0 500 1000 1500

1965

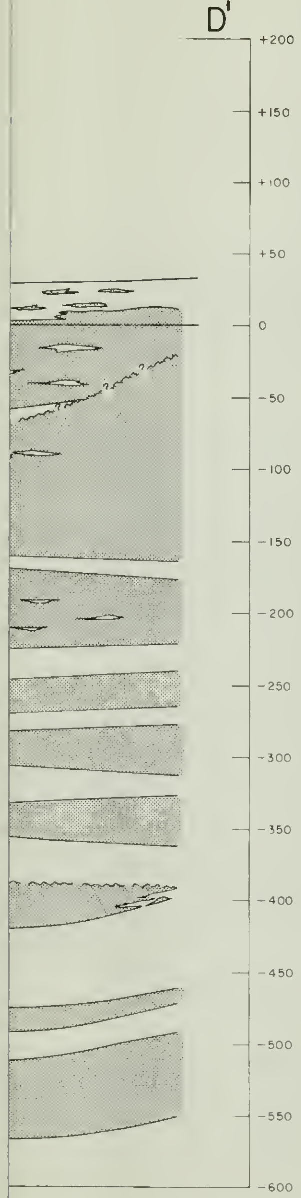


GEOLOGIC SECTION C-C'- ALONG BEACH BOULEVARD

DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP ORANGE COUNTY

GEOLOGIC SECTION C-C'



LEGEND

AQUIFER
SAND OR SAND AND CLAY

AQUICLUDE
CLAY, SILT, SANDY CLAY OR SANDY SILT

AQUIFER
SAND OR GRAVEL WITH CLAY OR SILT LENSES

AQUICLUDE
CLAY OR SILT WITH SAND OR GRAVEL LENSES

AQUIFER SALINITY
100–500 PPM CHLORIDE ION CONCENTRATION IN 1963

UNCONFORMITY

SOURCES OF SUBSURFACE GEOLOGIC DATA

5S/11W-36B2

WATER WELL WITH DRILLERS LOG

NOTE: LOCATION OF GEOLOGIC SECTIONS ARE SHOWN ON PLATE 4

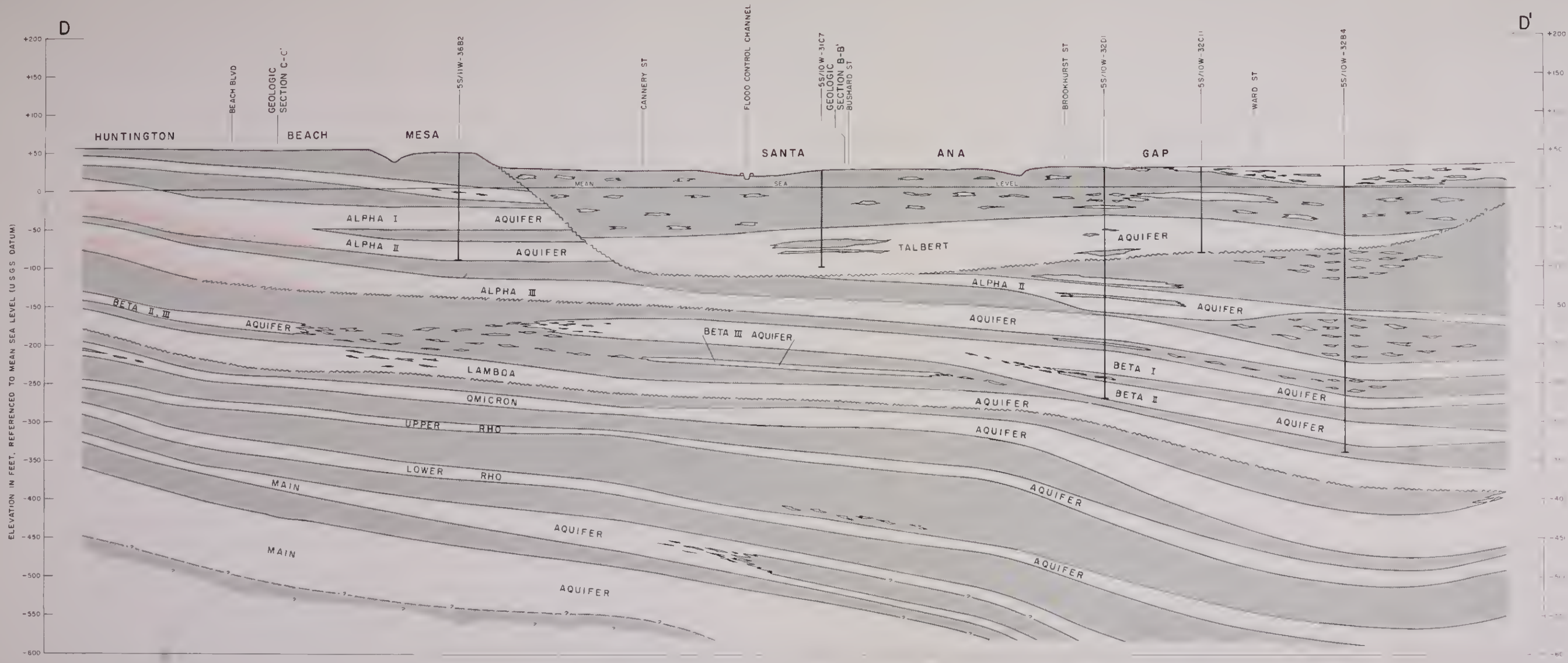
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

GEOLOGIC SECTION D–D'

HORIZONTAL SCALE OF FEET
500 0 500 1000 1500

1965



GEOLOGIC SECTION D-D' — EASTWARD FROM HUNTINGTON BEACH MESA ALONG TALBERT AVE.

LEGEND

AQUIFER
SAND OR SAND AND CLAY

AQUICLUDE
CLAY, SILT, SANDY CLAY OR SANDY SILT

AQUIFER
SAND OR GRAVEL WITH CLAY OR SILT LENSES

AQUICLUDE
CLAY OR SILT WITH SAND OR GRAVEL LENSES

AQUIFER SALINITY
100-500 PPM CHLORIDE ION CONCENTRATION IN 1963

UNCONFORMITY

SOURCES OF SUBSURFACE GEOLOGIC DATA

5S/11W-36B2
WATER WELL WITH DRILLERS LOG

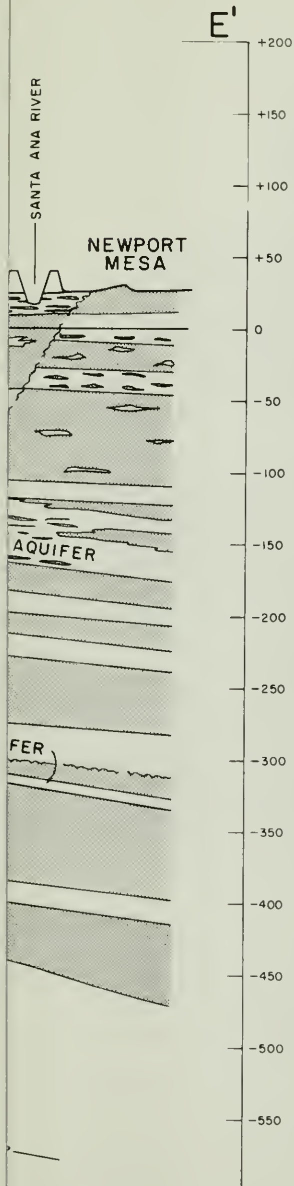
NOTE LOCATION OF GEOLOGIC SECTIONS ARE SHOWN ON PLATE 4

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

GEOLOGIC SECTION D-D'

HORIZONTAL SCALE OF FEET
500 0 1500



LEGEND

AQUIFER
SAND OR SAND AND CLAY

AQUICLUDE
CLAY, SILT, SANDY CLAY OR SANDY SILT

AQUIFER
SAND OR GRAVEL WITH CLAY OR SILT LENSES

AQUICLUDE
CLAY OR SILT WITH SAND OR GRAVEL LENSES

AQUIFER SALINITY
100-500 PPM CHLORIDE ION CONCENTRATION IN 1963

UNCONFORMITY

SOURCES OF SUBSURFACE GEOLOGIC DATA

SA-14 E S

DWR EXLORATORY WELL WITH ELECTRIC AND LITHOLOGIC LOG
("ES" DENOTES LOCATION OF PALEONTOLOGICAL MARKER, ELPHIDIUM SPINATUM)

NOTE: LOCATION OF GEOLOGIC SECTIONS ARE SHOWN ON PLATE 4

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

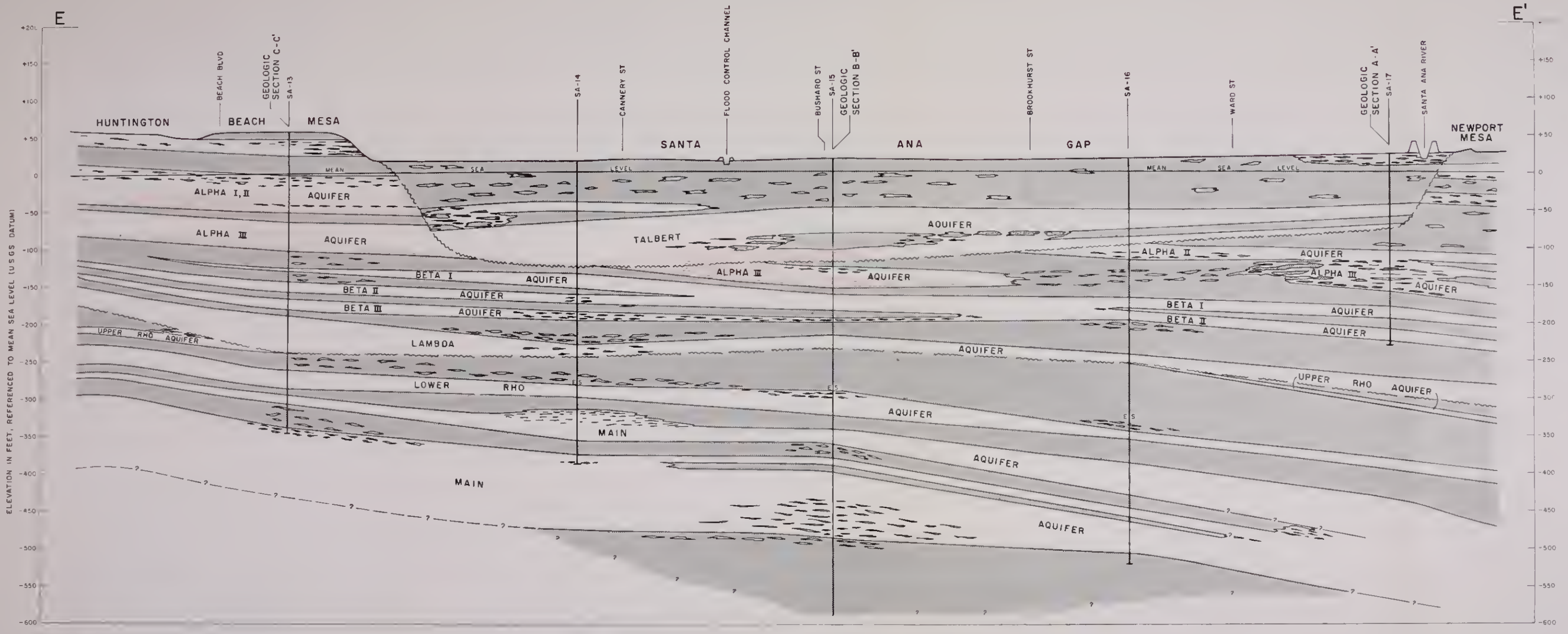
GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

GEOLOGIC SECTION E-E'

HORIZONTAL SCALE OF FEET

500 0 500 1000 1500

1965



GEOLOGIC SECTION E-E' - ALONG ELLIS AVE., FROM HUNTINGTON BEACH MESA TO NEWPORT MESA

LEGEND

AQUIFER
SAND OR SAND AND CLAY

AQUICLUDE
CLAY SILT, SANDY CLAY OR SANDY SILT

AQUIFER
SAND OR GRAVEL WITH CLAY OR SILT LENSES

AQUICLUDE
CLAY OR SILT WITH SAND OR GRAVEL LENSES

AQUIFER SALINITY
100-500 PPM CHLORIDE ION CONCENTRATION IN 1963

UNCONFORMITY

SOURCES OF SUBSURFACE GEOLOGIC DATA

SA-14
E S

GAP EXPLORATORY WELL WITH ELECTRIC AND LITHOLOGIC LOGS
("E S" DENOTES LOCATION OF PALEONTOLOGICAL MARKER ELPHIDIUM SPINATUM)

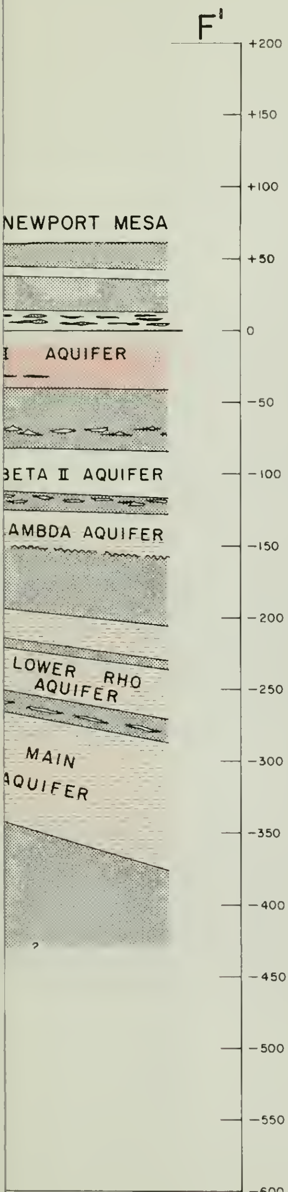
NOTE LOCATION OF GEOLOGIC SECTIONS ARE SHOWN ON PLATE 4

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

GEOLOGIC SECTION E-E'

HORIZONTAL SCALE OF FEET
500 1500



LEGEND

- AQUIFER — SAND OR SAND AND CLAY
- AQUICLUDE — CLAY, SILT, SANDY CLAY OR SANDY SILT
- AQUIFER — SAND OR GRAVEL WITH CLAY OR SILT LENSES
- AQUICLUDE — CLAY OR SILT WITH SAND OR GRAVEL LENSES
- AQUIFER SALINITY — 100-500 PPM CHLORIDE ION CONCENTRATION IN 1963
- AQUIFER SALINITY — GREATER THAN 500 PPM CHLORIDE ION CONCENTION IN 1963
- T | A FAULT — (LETTERS DENOTE RELATIVE MOVEMENT, T = TOWARD, A = AWAY)
- UNCONFORMITY

SOURCES OF SUBSURFACE GEOLOGIC DATA

- 6S/11W-2Rc — OIL WELL WITH ELECTRIC LOG (DASHED WHERE LOG IS UNAVAILABE)
- SA-23, E S — DWR EXLORATORY WELL WITH ELECTRIC AND LITHOLOGIC LOG. ("E S" DENOTES LOCATION OF PALEONTOLOGICAL MARKER, ELPHIDIUM SPINATUM)

NOTE: LOCATION OF GEOLOGIC SECTIONS ARE SHOWN ON PLATE 4

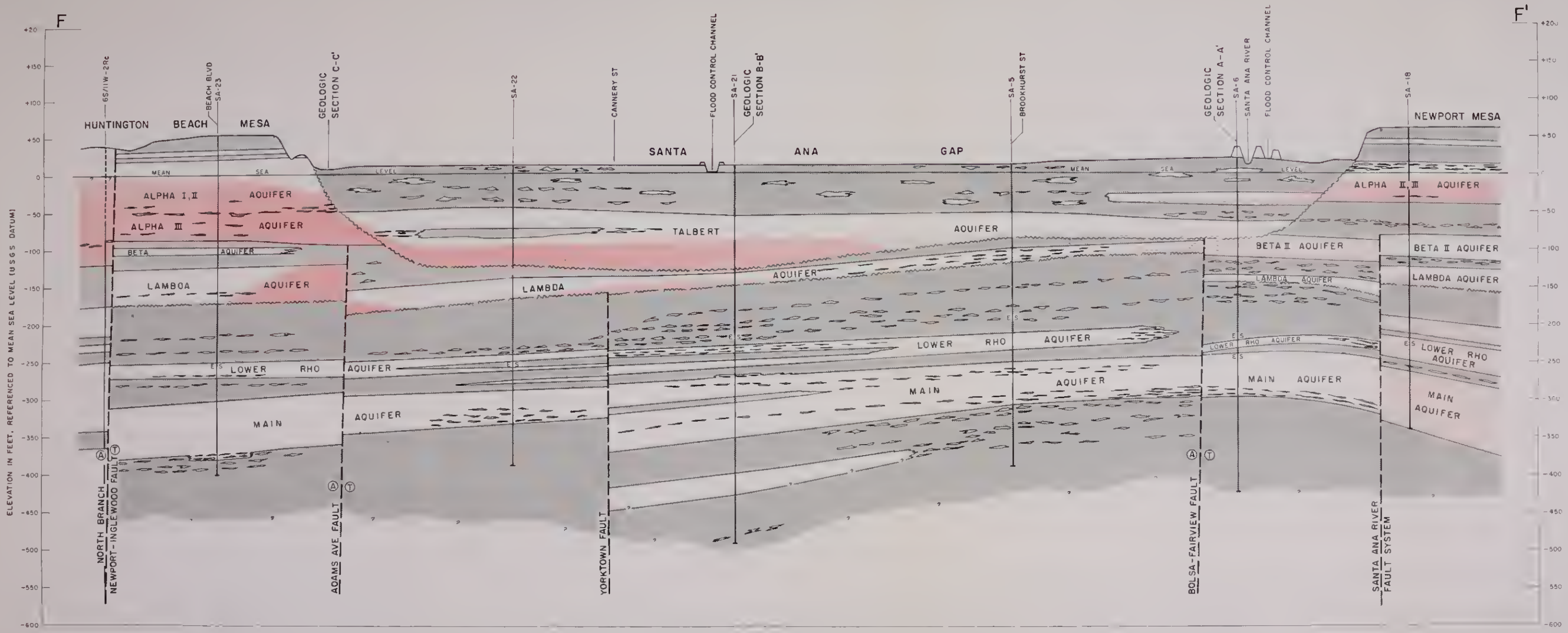
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

GEOLOGIC SECTION F-F'

HORIZONTAL SCALE OF FEET
500 0 500 1000 1500

1965



LEGEND

- AQUIFER — SAND OR SAND AND CLAY
- AQUICLUDE — CLAY, SILT, SANDY CLAY OR SANDY SILT
- AQUIFER — SAND OR GRAVEL WITH CLAY OR SILT LENSES
- AQUICLUDE — CLAY OR SILT WITH SAND OR GRAVEL LENSES
- AQUIFER SALINITY — 100–500 PPM CHLORIDE ION CONCENTRATION IN 1963
- AQUIFER SALINITY — GREATER THAN 500 PPM CHLORIDE ION CONCENTION IN 1963
- FAULT — (LETTERS DENOTE RELATIVE MOVEMENT, T = TOWARD A = AWAY)
- UNCONFORMITY

SOURCES OF SUBSURFACE GEOLOGIC DATA

- 6S/11W-2Rc — OIL WELL WITH ELECTRIC LOG (DASHED WHERE LOG IS UNAVAILABE)
- SA-23 — DWR EXLORATORY WELL WITH ELECTRIC AND LITHOLOGIC LOG ("E.S." DENOTES LOCATION OF PALEONTOLOGICAL MARKER, ELPHIDIUM SPINATUM)

NOTE: LOCATION OF GEOLOGIC SECTIONS ARE SHOWN ON PLATE 4

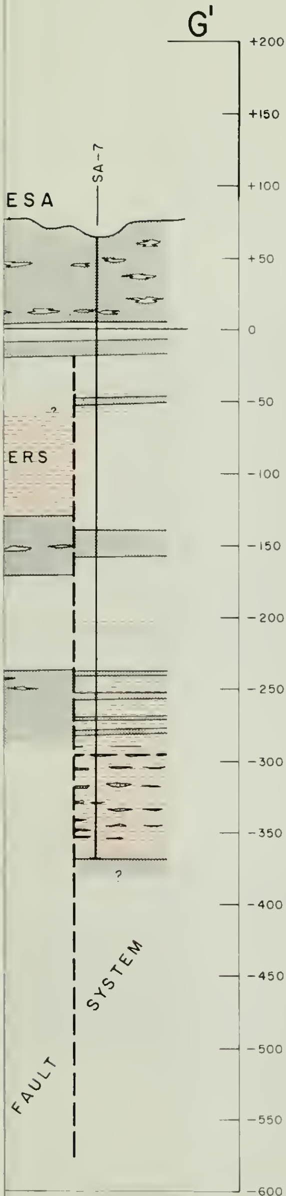
GEOLOGIC SECTION F-F' — ALONG YORKTOWN AVE FROM HUNTINGTON BEACH MESA TO NEWPORT MESA

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

GEOLOGIC SECTION F-F'

HORIZONTAL SCALE IN FEET



LEGEND

AQUIFER
SAND OR SAND AND CLAY

AQUICLUDE
CLAY, SILT, SANDY CLAY OR SANDY SILT

AQUIFER
SAND OR GRAVEL WITH CLAY OR SILT LENSES

AQUICLUDE
CLAY OR SILT WITH SAND OR GRAVEL LENSES

AQUIFER SALINITY
100-500 PPM CHLORIDE ION CONCENTRATION IN 1963

AQUIFER SALINITY
GREATER THAN 500 PPM CHLORIDE ION CONCENTION IN 1963

T | A FAULT
(LETTERS DENOTE RELATIVE MOVEMENT, T = TOWARD, A = AWAY)

UNCONFORMITY

SOURCES OF SUBSURFACE GEOLOGIC DATA

6S/IW-INo
OIL WELL WITH ELECTRIC LOG
(DASHED WHERE LOG IS UNAVAILABE)

SA-24
E S
DWR EXLORATORY WELL WITH ELECTRIC AND LITHOLOGIC LOG
("E S" DENOTES LOCATION OF PALEONTOLOGICAL MARKER, ELPHIDIUM SPINATUM)

NOTE: LOCATION OF GEOLOGIC SECTIONS ARE SHOWN ON PLATE 4

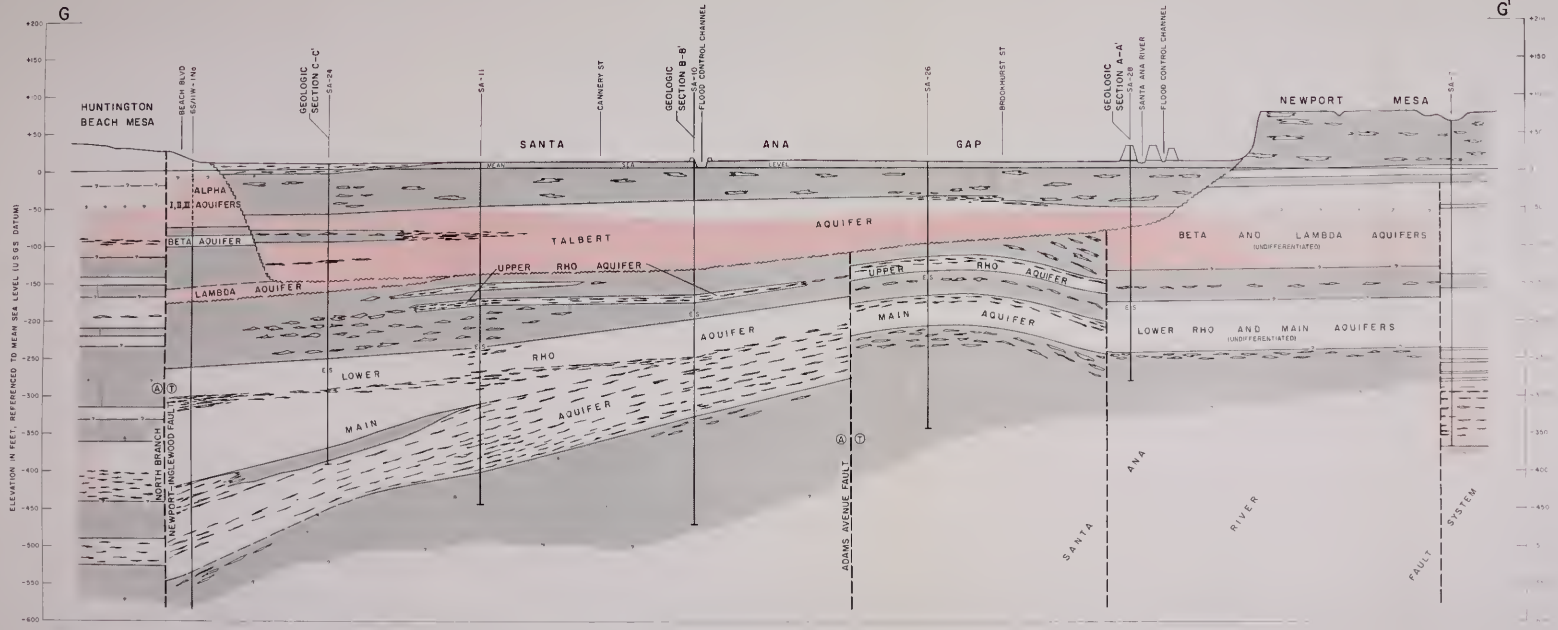
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

GEOLOGIC SECTION G-G'

HORIZONTAL SCALE OF FEET
500 0 500 1000 1500

1965



LEGEND

- AQUIFER — SAND OR SAND AND CLAY
- AQUICLUDE — CLAY, SILT, SANDY CLAY OR SANDY SILT
- AQUIFER — SAND OR GRAVEL WITH CLAY OR SILT LENSES
- AQUICLUDE — CLAY OR SILT WITH SAND OR GRAVEL LENSES
- AQUIFER SALINITY — 100-500 PPM CHLORIDE ION CONCENTRATION IN 1963
- AQUIFER SALINITY — GREATER THAN 500 PPM CHLORIDE ION CONCENTON IN 1963
- T | A FAULT — LETTERS DENOTE RELATIVE MOVEMENT, T = TOWARD, A = AWAY
- UNCONFORMITY

SOURCES OF SUBSURFACE GEOLOGIC DATA

- 6S/11W-1No — OIL WELL WITH ELECTRIC LOG (DASHED WHERE LOG IS UNAVAILABLE)
- SA-24, E.S — DWR EXPLORATORY WELL WITH ELECTRIC AND LITHOLOGIC LOG ("E.S" DENOTES LOCATION OF PALEONTOLOGICAL MARKER, ELPHIDIUM SPINATUM)

NOTE: LOCATION OF GEOLOGIC SECTIONS ARE SHOWN ON PLATE 4

GEOLOGIC SECTION G-G'— ALONG INDIANAPOLIS AVE., FROM HUNTINGTON BEACH MESA TO NEWPORT MESA

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

GEOLOGIC SECTION G-G'

HORIZONTAL SCALE OF FEET

LEGEND OF LITHOLOGY

SILT AND CLAY

SAND

GRAVEL

STATE OF CALIFORNIA
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SANTA ANA GAP, ORANGE COUNTY

GENERALIZED GEOLOGIC COLUMN

AGE	GEOLOGIC UNITS AND MAX. THICKNESS	GRAPHIC LITHOLOGY	AQUIFER UNITS	MAXIMUM THICKNESS IN FT.	GENERAL LITHOLOGY AND WATER-BEARING CHARACTER OF SEDIMENTS	GENERAL MICROPALEONTOLOGICAL CORRELATION ZONES
Recent	(Recent Deposits) (180')			100	Silt, organic silt, and sandy clay, with interbedded peat, shell fragments and thin sand lenses.	
			Talbert	110	Fine to coarse sand, fine to very coarse gravel and boulder with lenses of silty clay, wood and shell fragments. High permeability. Merged locally with the Alpha I, II, and III zones, Beta I and II zones and Lambda aquifer. Subject to saline intrusion.	Ostracods and Trochammina species
			Unconformity			
Late Pleistocene	Lakewood Formation (Upper Pleistocene Deposits) (400')			35	Silt and sandy clay with thin sand lenses. Locally cemented.	Streblus and Elphidium species
			Alpha I	50	Alpha I, II, and III: Fine to coarse sand and gravel, with peaty clay stringers. Moderate to high permeability. Merged with each other. Subject to saline intrusion. Separated by aquicludes of silt and sandy, silty clay with occasional thin gravel stringers.	
				85		
			Alpha II	30		
				65		
			Alpha III	60		
			Local Unconformity			Barren
				30		
			Beta I	40	Beta I, II, and III: Fine to coarse sand and fine gravel, with clay stringers. Moderate to high permeability. Locally merged with each other. Subject to saline intrusion. Separated by aquicludes of silt, sandy and silty clay, with thin sand lenses. Wood and shell fragments in clay section below Beta.	
			Beta II	15		
			Beta III	15		
				45		
			Lambda	50	Fine to coarse sand and fine gravel, with silty clay stringers. Moderate to high permeability. Locally merged with the Omicron and Upper Rho aquifers. Subject to saline intrusion.	
			Unconformity			
Early Pleistocene	San Pedro Formation (Lower Pleistocene Deposits) (700')			130	Sandy clay and sand lenses with shell fragments.	Nonionella species Elphidium spinatum
			Omicron	75	Sand and gravel with silt stringers. Moderate permeability. Subject to saline intrusion.	Cassidulina limbata and Angulogerina angulosa
				55	Silt and clay with sand lenses.	
			Upper Rho	30	Sand and gravel with silt and clay stringers. Moderate permeability. Subject to saline intrusion.	
				95	Silty clay and clay, with thin sand and gravel lenses, and wood and shell fragments.	Elphidium spinatum
			Lower Rho	50	Relatively uniform, fine to coarse sand and fine gravel. Moderate permeability. Merged locally with the Main aquifer.	
				65	Silt and clay with sand lenses and peat stringers.	
			Main	200	Sand and gravel with thin interbedded silt and silty clay members. Moderate permeability. (Contains brackish to saline waters beneath portions of Newport Mesa and seaward of main fault trace. Most important Lower Pleistocene aquifer in the area.)	
				400	Silty clay and clay, with sand and gravel lenses, and wood and shell fragments.	Bryozoa and Cassidulina limbata
		?	Local Unconformity			
Late Pliocene	Upper Pico Formation (Upper Pliocene Deposits) (1,000')			1000	Silt, clayey silt and partially cemented sandstone, with lenses of fine to medium sand. Moderate to low permeability. Localized fresh water.	Uvigerina peregrina, with Epistominella pacifica, and Bolivina interjuncta

LEGEND OF LITHOLOGY

SILT AND CLAY

SAND

GRAVEL

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GENERALIZED GEOLOGIC COLUMN

LEGEND OF LITHOLOGY

CLAY

SILT

SAND

GRAVEL

STATE OF CALIFORNIA
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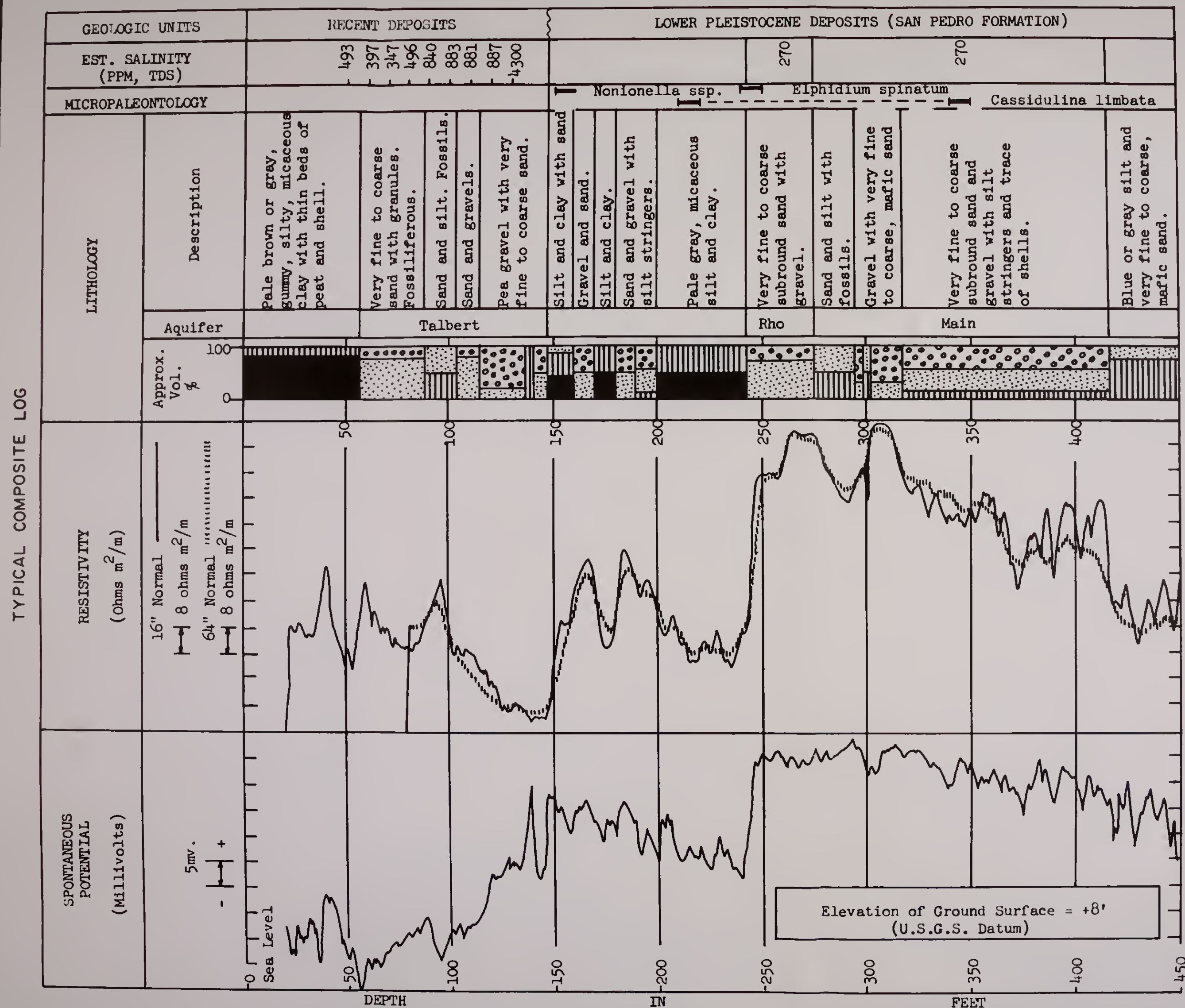
TYPICAL COMPOSITE LOG

DWR EXPLORATORY WELL 6S/11W-12B2
(SA-11)



STATE OF CALIFORNIA
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DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
GROUND WATER BASIN PROTECTION PROJECTS
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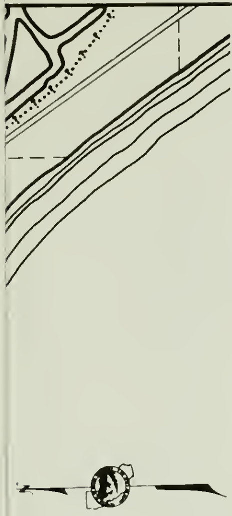
SANTA ANA GAP, ORANGE COUNTY

TYPICAL COMPOSITE LOG
DWR EXPLORATORY WELL 6S/11W-12B2
(SA-11)



LEGEND

— -500 — LINES OF EQUAL ELEVATION IN FEET, ON THE TOP OF MAIN AQUIFER (DASHED WHERE CONTROL IS POOR)

AREA OF MERGENCE BETWEEN LOWER RHO AND MAIN AQUIFERS

U / D FAULT (DASHED WHERE APPROXIMATELY LOCATED; U, UPTHROWN SIDE; D, DOWNTHROWN SIDE)

CONCEALED FAULT, SHOWING RELATIVE MOVEMENT

—?—?··· PROBABLE FAULT (DOTTED WHERE CONCEALED)

NOTE: ELEVATION IN FEET, REFERENCED TO MEAN SEA LEVEL (U.S.G.S. DATUM)

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GROUND WATER BASIN PROTECTION PROJECTS
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LINES OF EQUAL ELEVATION TOP OF THE MAIN AQUIFER

SCALE OF FEET

1000 0 1000 2000 3000

1965

LEGEND

—-500— LINES OF EQUAL ELEVATION IN FEET, ON THE TOP OF MAIN AQUIFER (DASHED WHERE CONTROL IS POOR)

AREA OF MERGENCE BETWEEN LOWER RHO AND MAIN AQUIFERS

FAULT (DASHED WHERE APPROXIMATELY LOCATED, U, UPTHROWN SIDE, D, DOWNTHROWN SIDE)

CONCEALED FAULT, SHOWING RELATIVE MOVEMENT

PROBABLE FAULT (DOTTED WHERE CONCEALED)

NOTE ELEVATION IN FEET, REFERENCED TO MEAN SEA LEVEL (U.S.G.S. DATUM)

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GROUND WATER BASIN PROTECTION PROJECTS
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SANTA ANA GAP, ORANGE COUNTY

LINES OF EQUAL ELEVATION
TOP OF THE MAIN AQUIFER

SCALE OF FEET
1000 0 1000 2000 3000

1965

LEGEND

— -20— —	LINES OF EQUAL ELEVATION IN FEET - TOP OF THE TALBERT AQUIFER (DASHED WHERE CONTROL IS POOR)
—-100—	LINES OF EQUAL ELEVATION IN FEET — BASE OF THE TALBERT AQUIFER (DASHED WHERE CONTROL IS POOR)
	APPROXIMATE LIMITS OF THE TALBERT AQUIFER
U / D	FAULT (DASHED WHERE APPROXIMATELY LOCATED, U, UPTHROWN SIDE; D, DOWNTHROWN SIDE)
	CONCEALED FAULT, SHOWING RELATIVE MOVEMENT
? ?	PROBABLE FAULT (DOTTED WHERE CONCEALED)

NOTE: ELEVATIONS IN FEET, REFERENCED TO MEAN SEA LEVEL (U S G S DATUM)

STATE OF CALIFORNIA
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GROUND WATER BASIN PROTECTION PROJECTS
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SANTA ANA GAP, ORANGE COUNTY

LINES OF EQUAL ELEVATION — TOP AND BASE OF THE TALBERT AQUIFER

SCALE OF FEET

1000 0 1000 2000 3000

1965

NEWPORT MESA
SANTA ANA RIVER FAULT SYSTEM
HUNTINGTON BEACH MESA
PACIFIC OCEAN
NEWPORT - INGLEWOOD FAULT
NORTH BRANCH
SOUTH BRANCH
FAULT
ORANGE COUNTY FLOOD CONTROL CHANNEL
PROPOSED SAN DIEGO FWY
T5S
T6S
R10W
R11W
VERANO
WARD
BROOKHURST
BUSHARD
CANNERY
NEWLAND
WARNER
SLATER
TALBERT
ELLIS
GARFIELD
YORKTOWN
BEACH BLVD
FAIRVIEW
ADAMS AVENUE
INDIANAPOLIS
ATLANTA
HAMILTON
BANNING
VICTORIA
COAST HWY
LEGEND
LINES OF EQUAL ELEVATION IN FEET - TOP OF THE TALBERT AQUIFER (DASHED WHERE CONTROL IS POOR)
-100 LINES OF EQUAL ELEVATION IN FEET - BASE OF THE TALBERT AQUIFER (DASHED WHERE CONTROL IS POOR)
APPROXIMATE LIMITS OF THE TALBERT AQUIFER
FAULT (DASHED WHERE APPROXIMATELY LOCATED, U, UPTHROWN SIDE D, DOWNTHROWN SIDE)
CONCEALED FAULT, SHOWING RELATIVE MOVEMENT
PROBABLE FAULT (DOTTED WHERE CONCEALED)
NOTE ELEVATIONS IN FEET, REFERENCED TO MEAN SEA LEVEL (U.S.G.S. DATUM)
STATE OF CALIFORNIA
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SOUTHERN DISTRICT
GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY
LINES OF EQUAL ELEVATION-
TOP AND BASE OF THE TALBERT AQUIFER
SCALE OF FEET
1000 0 1000 2000 3000
1965

LEGEND

AREA OF HYDRAULIC CONTINUITY BETWEEN TALBERT AQUIFER AND AQUIFER(S) LISTED

- ALPHA II
- ALPHA III
- BETA I
- BETA II
- BETA I, II MERGED
- BETA, LAMBDA MERGED
- LAMBDA

AREA OF HYDRAULIC CONTINUITY BETWEEN LAMBDA AQUIFER AND UPPER RHO AQUIFER

U / D — FAULT (DASHED WHERE APPROXIMATELY LOCATED, U, UPTHROWN SIDE; D, DOWNTHROWN SIDE)

CONCEALED FAULT, SHOWING RELATIVE MOVEMENT

— ? — ? • • • PROBABLE FAULT (DOTTED WHERE CONCEALED)

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GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
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AREAS OF HYDRAULIC CONTINUITY BETWEEN AQUIFERS

SCALE OF FEET

1000 0 1000 2000 3000

1965

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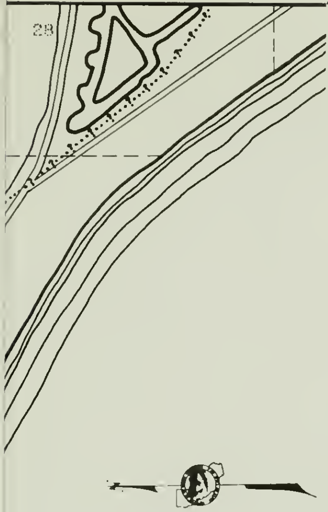
GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

AREAS OF HYDRAULIC CONTINUITY BETWEEN AQUIFERS



LEGEND

—-200—- LINES OF EQUAL ELEVATION IN FEET, ON THE BASE OF THE LOWEST ZONE SUBJECT TO SALINE WATER INTRUSION (DASHED WHERE CONTROL IS POOR)

APPROXIMATE LIMITS OF AREA IN WHICH THE LAMBOA AQUIFER IS THE LOWEST ZONE SUBJECT TO SALINE WATER INTRUSION

U/D FAULT (DASHED WHERE APPROXIMATELY LOCATED; U, UPTHROWN SIDE, D, DOWNTHROWN SIDE.)

CONCEALED FAULT, SHOWING RELATIVE MOVEMENT

—?—?····· PROBABLE FAULT (DOTTED WHERE CONCEALED)

NOTE ELEVATION IN FEET, REFERENCED TO MEAN SEA LEVEL (U.S.G.S DATUM)

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LINES OF EQUAL ELEVATION - BASE OF THE LOWEST ZONE SUBJECT TO SALINE-WATER INTRUSION

SCALE OF FEET

1000 0 1000 2000 3000

1965

LEGEND

LINES OF EQUAL ELEVATION IN FEET ON THE BASE OF THE LOWEST ZONE SUBJECT TO SALINE WATER INTRUSION (DASHED WHERE CONTROL IS POOR)

APPROXIMATE LIMITS OF AREA IN WHICH THE LAMBDA AQUIFER IS THE LOWEST ZONE SUBJECT TO SALINE WATER INTRUSION

FAULT (DASHED WHERE APPROXIMATELY LOCATED, U UPTHROWN SIDE D, DOWNTHROWN SIDE

CONCEALED FAULT SHOWING RELATIVE MOVEMENT

PROBABLE FAULT (DOTTED WHERE CONCEALED)

NOTE ELEVATION IN FEET, REFERENCED TO MEAN SEA LEVEL (USGS DATUM)

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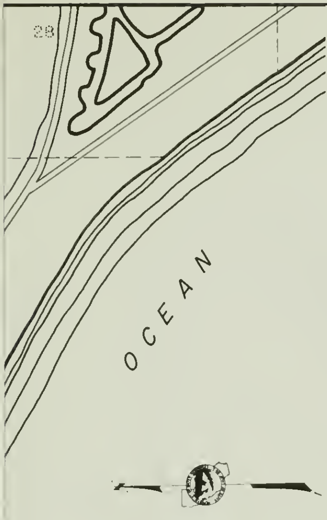
GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

LINES OF EQUAL ELEVATION - BASE OF THE LOWEST ZONE SUBJECT TO SALINE-WATER INTRUSION

SCALE OF FEET
1000 0 1000 2000 3000

1965



LEGEND

-5 LINES OF EQUAL PIEZOMETRIC ELEVATION IN FEET – TALBERT AQUIFER (DASHED WHERE CONTROL IS POOR)

APPROXIMATE LIMITS OF THE TALBERT AQUIFEP

NOTE ELEVATIONS IN FEET, REFERENCED TO MEAN SEA LEVEL (USGS. DATUM)

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GROUND WATER BASIN PROTECTION PROJECTS
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LINES OF EQUAL PIEZOMETRIC ELEVATION TALBERT AQUIFER SPRING 1963

SCALE OF FEET
1000 0 1000 2000 3000

1965

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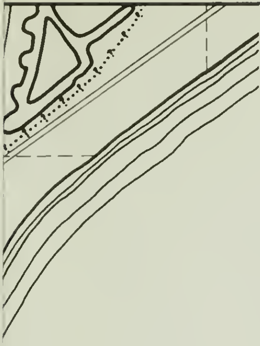
GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

LINES OF EQUAL PIEZOMETRIC ELEVATION
TALBERT AQUIFER
SPRING 1963



LEGEND

—5— LINES OF EQUAL PIEZOMETRIC ELEVATION IN FEET - ALPHA AQUIFER (DASHED WHERE CONTROL IS POOR)

LINES OF EQUAL PIEZOMETRIC ELEVATION IN FEET - MAIN AQUIFER (DASHED WHERE CONTROL IS POOR)

APPROXIMATE LIMITS OF THE ALPHA AQUIFER

U / D FAULT (DASHED WHERE APPROXIMATELY LOCATED; U, UPTHROWN SIDE; D, DOWNTHROWN SIDE)

CONCEALED FAULT, SHOWING RELATIVE MOVEMENT

—?—?.... PROBABLE FAULT (DOTTED WHERE CONCEALED)

NOTE. ELEVATION IN FEET, REFERENCED TO MEAN SEA LEVEL (USGS DATUM)

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GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
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LINES OF EQUAL PIEZOMETRIC ELEVATION ALPHA AND MAIN AQUIFERS SPRING 1963

SCALE OF FEET
1000 0 1000 2000 3000

1965

LEGEND

LINES OF EQUAL PIEZOMETRIC ELEVATION IN FEET ALPHA AQUIFER (DASHED WHERE CONTROL IS POOR)

LINES OF EQUAL PIEZOMETRIC ELEVATION IN FEET-MAIN AQUIFER (DASHED WHERE CONTROL IS POOR)

APPROXIMATE LIMITS OF THE ALPHA AQUIFER

FAULT (DASHED WHERE APPROXIMATELY LOCATED, U UPTHROWN SIDE, D, DOWNTHROWN SIDE)

CONCEALED FAULT, SHOWING RELATIVE MOVEMENT

PROBABLE FAULT (DOTTED WHERE CONCEALED)

NOTE ELEVATION IN FEET REFERENCED TO MEAN SEA LEVEL (U.S.G.S. DATUM)

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GROUND WATER BASIN PROTECTION PROJECTS
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SANTA ANA GAP, ORANGE COUNTY

LINES OF EQUAL PIEZOMETRIC ELEVATION ALPHA AND MAIN AQUIFERS SPRING 1963

SCALE OF FEET

1000 0 1000 2000 3000

965

LEGEND

SANTA ANA GAP

— 50 — LINES OF EQUAL CHLORIDE ION CONCENTRATION IN PARTS PER MILLION FOR 1963 IN THE TALBERT AQUIFER

— 50 — LINES OF EQUAL CHLORIDE ION CONCENTRATION IN PARTS PER MILLION PRIOR TO 1963 IN THE TALBERT AQUIFER

TALBERT — AREA UNDERLAIN BY WATERS WITH GREATER THAN 5000 PARTS PER MILLION CHLORIDE ION CONCENTRATION IN 1963, DENOTING AQUIFER AFFECTED.

HUNTINGTON BEACH AND NEWPORT MESAS

ALPHA — AREA UNDERLAIN BY WATERS OF 100-500 PARTS PER MILLION CHLORIDE ION CONCENTRATION IN 1963, DENOTING AQUIFER AFFECTED

ALPHA — AREA UNDERLAIN BY WATERS OF GREATER THAN 500 PARTS PER MILLION CHLORIDE ION CONCENTRATION IN 1963, DENOTING AQUIFER AFFECTED

● A1 — LOCATION OF WATER WELL WITH GROUND WATER ANALYSIS

B2 (SA-11) — LOCATION OF EXPLORATORY WELL WITH GROUND WATER ANALYSIS, B2 DENOTES STATE WELL NUMBER (SA-11 DENOTES DWR TEST WELL NUMBER)

Q7,8 (OCWD T-3) — LOCATION OF EXPLORATORY WELL WITH GROUND WATER ANALYSIS, Q7,8 DENOTE STATE WELL NUMBER (OCWD T-3 DENOTES ORANGE COUNTY WATER DISTRICT TEST WELL NUMBER)

L4,5,6 (SA-12) — LOCATION OF EXPLORATORY WELL WITH GROUND WATER ANALYSIS, L 4,5,6 DENOTE STATE WELL NUMBERS (SA-12 DENOTES DWR TEST WELL NUMBER)

STATE OF CALIFORNIA
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GROUND WATER BASIN PROTECTION PROJECTS
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CHLORIDE ION CONCENTRATION IN GROUND WATER

SCALE OF FEET

1000 0 1000 2000 3000

1965

STATE OF CALIFORNIA
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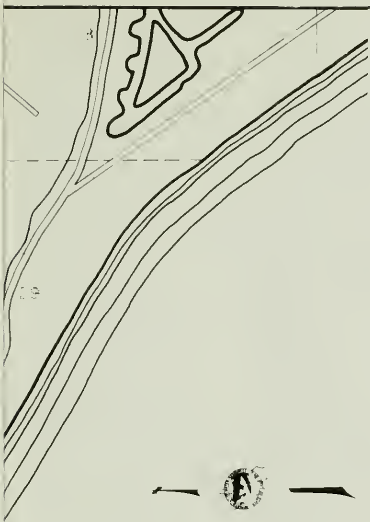
SOUTHERN DISTRICT

GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

CHLORIDE ION CONCENTRATION IN GROUND WATER



STATE OF CALIFORNIA
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DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT

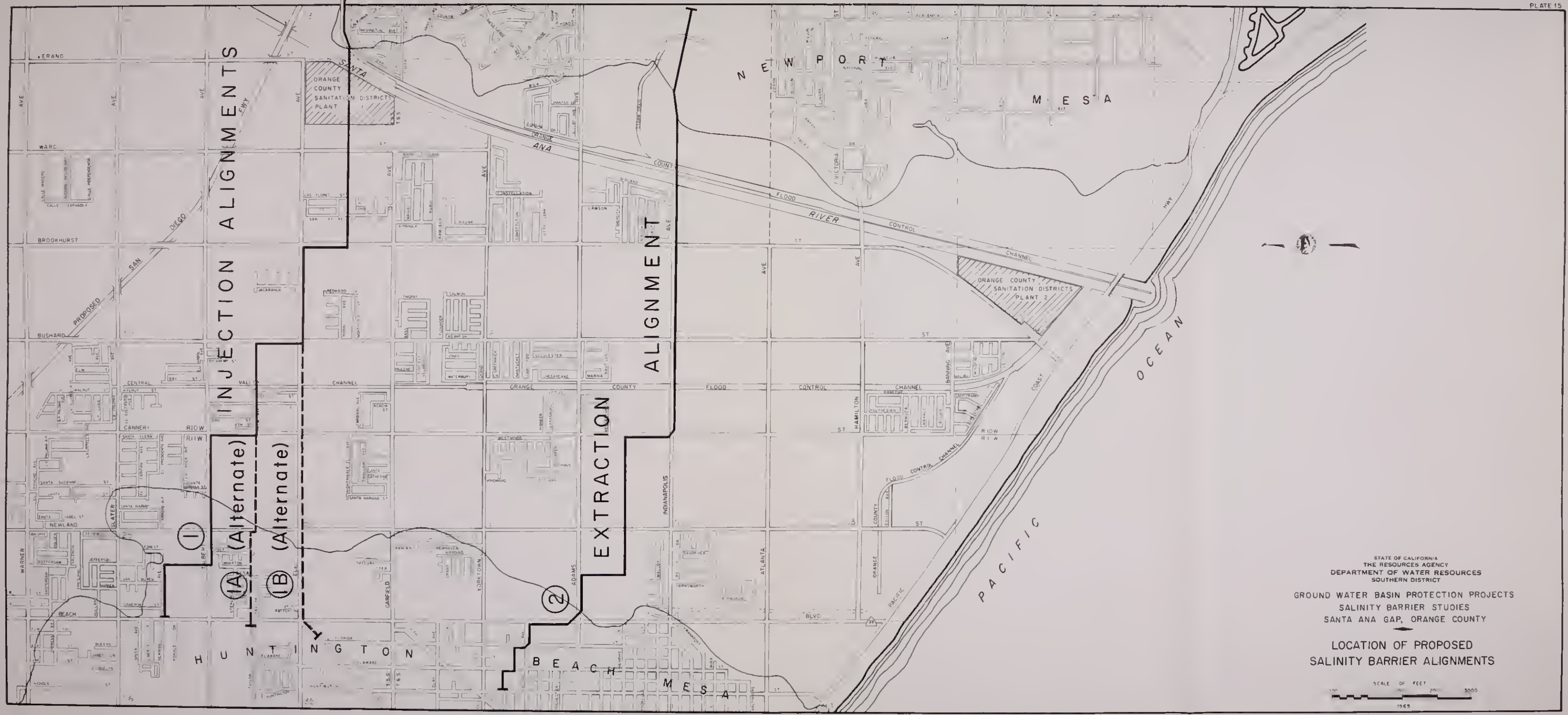
GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY

LOCATION OF PROPOSED SALINITY BARRIER ALIGNMENTS

SCALE OF FEET
1000 0 1000 2000 3000

1965

PLATE 15


INJECTION ALIGNMENTS
EXTRACTION ALIGNMENT
1
IA (Alternate)
IB (Alternate)
2
NEWPORT MESA
HUNTINGTON BEACH MESA
PACIFIC OCEAN
ORANGE COUNTY SANITATION DISTRICTS PLANT
ORANGE COUNTY SANITATION DISTRICTS PLANT 2
SANTA ANA RIVER
ORANGE COUNTY FLOOD CONTROL CHANNEL
PROPOSED SAN DIEGO FWY
COAST HWY
BROOKHURST
BUSHARD
WARNER
SLATER
NEWLAND
GARFIELD
YORKTOWN
ADAMS
INDIANAPOLIS
ATLANTA
HAMILTON
VICTORIA
BEACH
BLVD
ORANGE
TALBERT
STATE OF CALIFORNIA
THE RESOURCES AGENCY
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SOUTHERN DISTRICT
GROUND WATER BASIN PROTECTION PROJECTS
SALINITY BARRIER STUDIES
SANTA ANA GAP, ORANGE COUNTY
LOCATION OF PROPOSED
SALINITY BARRIER ALIGNMENTS
SCALE OF FEET
3000
1965

Call Number:

482529
California. Dept.
of Water Resources.
Bulletin.

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no.147:1